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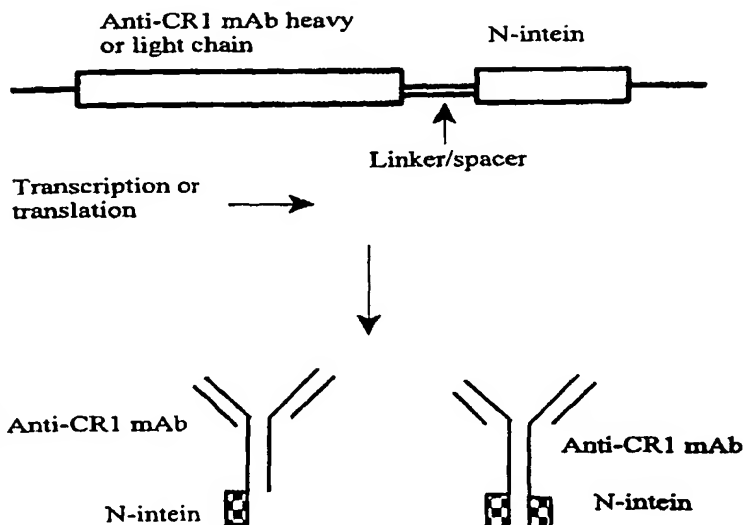
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(54) Title: METHOD OF PRODUCING BIOSPECIFIC MOLECULES BY PROTEIN TRANS-SPICING



(57) Abstract: The invention provides methods of using protein trans-splicing for the production of bispecific molecule which has a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds an antigenic molecule present in the circulatory system of a mammal. The invention also provides bispecific molecules produced by protein trans-splicing. The bispecific molecules of the invention can be used for the clearance of pathogenic antigenic molecules from the circulatory system of a mammal. The invention further provides methods of using protein trans-splicing for the production of polyclonal libraries of bispecific molecules, which comprise populations of bispecific molecules with different antigen recognition specificities. Such

polyclonal libraries of bispecific molecules can be used for targeting multiple epitopes of a pathogenic antigenic molecule and/or multiple variants of a pathogenic antigenic molecule.

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**METHOD OF PRODUCING BISPECIFIC MOLECULES BY PROTEIN  
TRANS-SPLICING**

5        This application claims the benefit of U.S. Provisional Patent Application No. 60/244,811, filed on November 1, 2000, which is incorporated herein by reference in its entirety.

**1. FIELD OF THE INVENTION**

10        The invention relates to methods of using protein trans-splicing for the production of bispecific molecules having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule present in the circulatory  
15        system of a mammal. The invention also relates to bispecific molecules produced by protein trans-splicing. The invention further relates to methods of using protein trans-splicing for the production of polyclonal libraries of bispecific molecules.

20

**2. BACKGROUND OF THE INVENTION**

      Primate erythrocytes, or red blood cells (RBC's), play an essential role in the clearance of antigens from the circulatory system. The formation of an immune complex in the circulatory system activates the complement factor C3b in  
25        primates and leads to the binding of C3b to the immune complex. The C3b/immune complex then binds to the type 1 complement receptor (CR1), a C3b receptor, expressed on the surface of erythrocytes via the C3b molecule attached to the immune complex. The immune complex is then chaperoned by the  
30        erythrocyte to the reticuloendothelial system (RES) in the liver and spleen for neutralization. The RES cells, most notably the fixed-tissue macrophages in the liver called Kupffer cells, recognize the C3b/immune complex and break this complex from the RBC by severing the C3b receptor-RBC  
35        junction, producing a liberated erythrocyte and a C3b/immune complex which is then engulfed by the Kupffer cells and is completely destroyed within subcellular organelles of the Kupffer cells. This pathogen clearance process, however, is

complement-dependent, i.e., confined to immune complexes recognized by the C3b receptor, and is ineffective in removing immune complexes which are not recognized by the C3b receptor.

5 Taylor et al. have discovered a complement independent method of removing pathogens from the circulatory system. Taylor et al. have shown that chemical crosslinking of a first monoclonal antibody (mAb) specific to a primate C3b receptor to a second monoclonal antibody specific to a  
10 pathogenic antigenic molecule creates a bispecific heteropolymeric antibody which offers a mechanism for binding a pathogenic antigenic molecule to a primate's C3b receptor without complement activation. (U.S. Patent Nos. 5,487,890; 5,470,570; and 5,879,679). It is found that the Fc portion  
15 of the mAb specific to C3b receptor plays an important role in the transfer of the erythrocyte-immune complex to an acceptor cell and the subsequent proteolysis of the erythrocyte-immune complex (Nardin et al., 1999, Molecular Immunology 36:827-835). Taylor et al. have shown that this  
20 complement-independent process can remove over 99% of pathogens from the circulation as compared to about 10-15% by the normal, complement-dependent, process.

The Taylor method, however, has certain shortcomings. Firstly, the chemistry of the cross-linking reaction is not very efficient. Typically, the yields of such chemical  
25 cross-linking reactions are only about 10% to 20%. As a result, a significant amount of purified mAbs or pathogen-binding moieties is lost during the chemical cross-linking step of the manufacturing process. For example, using  
30 standard chemical cross-linking agents (such as Pierce's SATA and sulfo-SMCC), 1 mg of pure mAb1 cross-linked to 1 mg of pure mAb2 will generate only between 0.2 to 0.4 mg of pure product mAb1 X mAb2. Secondly, the bispecific molecule produced by chemical cross-linking contains a chemical cross-linker fragment which can be immunogenic. The immunogenicity  
35 of the cross-linker can be disadvantageous when re-administering Taylor's bispecific molecule to the same

individual because the individual will generate an immune response against the cross-linker moiety and, upon re-exposure of the same individual to another dose of the bispecific molecule, the individual might mount a vigorous  
5 immune response against it, reducing potential therapeutic benefits that the bispecific molecule would otherwise provide. Thirdly, the cross-linking process described in the Taylor patents is not site-specific, and consequently, may decrease somewhat the functionality of the mAbs or pathogen  
10 recognition domains. Therefore, there is a need for a more efficient method for the production of bispecific molecules.

Protein splicing is a post-translational protein processing reaction that involves the excision of an intervening sequence, the internal protein domain or intein, from a precursor molecule and the concomitant ligation of the  
15 two flanking sequences, the N- and C-terminal external protein domains or N- and C-exteins, to form a functional new protein (see, for example, Paulus, 1998, Chem. Soc. Rev. 27:375-386). The excision and ligation are catalyzed by the  
20 amino acid residues within an intein plus the first residue at the N-terminus of the C-extein. The residues responsible for splicing are the approximately 100 amino acids at the intein N-terminus and the approximately 35 amino acids at the intein C-terminus (Lew et al., 1998, J. Biol. Chem. 273:15887-15890; Noren et al., 2000, Angew. Chem. Int. Ed.  
25 39:450-466). A typical protein splicing reaction involves 4 nucleophilic displacements by the 3 conserved splice junction residues: a cysteine (Cys), serine (Ser), or threonine (Thr) at the intein N-terminus, an asparagine (Asn) at the intein C-terminus, and a Cys, Ser, or Thr at the downstream C-extein  
30 N-terminus (Perle et al., 1997, Nucleic Acids Res. 25:1087-1093; Southworth et al., 1998, EMBO J. 17:918-926). Other intein residues may also assist in the nucleophilic displacement (Perle et al., 1997, Nucleic Acids Res. 25:1087-1093; Southworth et al. 1998, EMBO J. 17:918-926). Protein  
35 splicing has been identified in a variety of species, including eucarya, eubacteria, and archaebacteria.



Inteins may also be split into N-terminal and C-terminal intein fragments that can reconstitute and undergo protein trans-splicing. A naturally occurring split intein system encoded in the DnaE gene of *Synechocystis* sp. PCC6803 (Ssp) was identified (Wu et al., 1998, Proc. Natl. Acad. Sci. USA 95:9226-9231). This split intein system was expressed in *E. coli* and was shown to exhibit trans-splicing activity in *E. coli* cells (Wu et al., 1998, Proc. Natl. Acad. Sci. USA 95:9226-9231). More recently, the Ssp DnaE split intein system has also been shown to mediate efficient *in vivo* and *in vitro* trans-splicing and cis-splicing in a foreign extein content (Evans et al., 2000, J. Biol. Chem. 275:9091-9094). Engineered split intein systems based on naturally occurring non-split intein systems have also been demonstrated, including the *in vitro* trans-splicing systems using purified N- and C-terminal fragments of the *Mycobacterium tuberculosis* (Mtu) RecA intein and the *Pyrococcus* sp. (Psp) Pol-1 intein (Mills et al., 1998, Proc. Natl. Acad. Sci. USA 95:3543-3548; Lew et al., 1998, J. Biol. Chem. 273:15887-15890; Southworth et al., 1998, EMBO J. 17:918-926). It is shown that the N- and C-terminal fragments of the Mtu RecA intein system can be reconstituted as an inactive disulfide-linked complex of the two intein fragments, which can subsequently undergo trans-splicing reaction by reduction of the disulfide bond.

Inteins and split inteins may also be modified for more efficient and/or controllable splicing and trans-splicing reactions. For example, splicing in chimeric precursors is usually less efficient than in native precursors, presumably due to impaired intein folding in a foreign extein content as evidenced by their temperature-dependent reactivity. (Noren et al., 2000, Angew. Chem. Int. Ed. 39:450-466) Evans et al. show that inclusion of 3 to 5 native extein residues in the N- and C-inteins of Ssp DnaE system may enhance trans-splicing and cis-splicing in a foreign extein content (Evans et al., 2000, J. Biol. Chem. 275:9091-9094). Alternatively, it may be desirable to choose exteins comprising proximal amino acid sequences that are similar to the native exteins.

The inteins themselves may also be modified. For example, it is shown that splicing proficiency in *E coli* is increased when the proline residue adjacent to the N-terminal Cys in the ribonucleoside diphosphate reductase gene of

5 Methanobacterium thermoautotrophicum is replaced with an alanine residue (Evans et al., 1999, J. Biol. Chem. 274:3923-3926). Inteins have also been modified by site-directed mutagenesis so that splicing reactions can be controlled by photochemistry (Cook et al., 1995, Angew. Chem. 107:1736-

10 1737; Cook et al., 1995, Angew. Chem. Int. Ed. Engl. 34:1629-1630; Noren et al., 1989, Science 244:182-188).

Means for fusing proteins and/or synthetic polypeptides based on protein splicing and trans-splicing have been reported (see, for example, Evans et al., 1999, Biopolymer

15 51:333-341; Evans et al., 1999, J. Biol. Chem. 274:3923-3926; Evans et al., 1999, J. Biol. Chem. 274:18359-18363). In vitro trans-splicing generally offers a more controlled means in utilizing protein splicing in protein synthesis. Reconstitution and trans-splicing in vitro also allows

20 ligation of exteins expressed in different cells. This has also allowed expression of proteins that are otherwise not possible in a single cell (Noren et al., 2000, Angew. Chem. Int. Ed. 39:450-466). On the other hand, in vivo trans-splicing may be more efficient in that the co-expressed

25 inteins may be less prone to misfolding, due both to more efficient reconstitution and/or the assistance of the powerful protein folding machinery present in a cell (Southworth et al., 1998, EMBO J. 17:918-926).

Discussion or citation of a reference herein shall not be construed as an admission that such reference is prior art

30 to the present invention.

### 3. SUMMARY OF THE INVENTION

The present invention relates to methods of producing a bispecific molecule having a first antigen recognition

35 portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic

molecule, using protein trans-splicing. In the present invention, the first antigen recognition portion is conjugated to the N-terminus of an N-intein of a suitable split intein to produce an N-intein first antigen recognition  
5 portion fragment, whereas the second antigen recognition portion is conjugated to the C-terminus of the C-intein of the split intein to produce a C-intein second antigen recognition portion fragment. The N-intein first antigen recognition portion fragment and the C-intein second antigen  
10 recognition portion fragment are then brought together such that they reconstitute and undergo trans-splicing to produce the bispecific molecule. The bispecific molecule of the present invention is useful in the clearance of pathogenic antigenic molecule from the circulatory system of a mammal.

15 The first antigen recognition portion of the present invention can be any molecule or fragment thereof having a C3b-like receptor binding domain and an effector domain. In a preferred embodiment, the first antigen recognition portion comprises an anti-CR1 monoclonal antibody. The first antigen  
20 recognition portion can also be a single chain Fv fragment fused to an Fc domain or a chimeric antibody having a C3b-like receptor binding domain and an effector domain.

The second antigen recognition portion of the present invention can be any molecule or fragment thereof that  
25 recognizes and binds a pathogenic antigenic molecule, e.g., a naturally occurring antigen, and/or any derivative or fragment thereof. The pathogenic antigenic molecule can be any substance that is present in the circulation that is potentially injurious to or undesirable in the subject to be  
30 treated, including but is not limited to proteins or drugs or toxins, autoantibodies or autoantigens, or a molecule of any infectious agent or its products. A pathogenic antigenic molecule is any molecule containing an antigenic determinant (or otherwise capable of being bound by a binding domain)  
35 that is or is part of a substance (e.g., a pathogen) that is the cause of a disease or disorder or any other undesirable condition. The second antigen recognition portion of the

invention can be any type of molecule, including but is not limited to peptide and polypeptide, nucleic acid, oligosaccharide, and organic small molecule.

The first and second antigen recognition portions of the bispecific molecule of the invention can be linked directly. The first and second antigen recognition portions of the bispecific molecule of the invention can also be linked via a suitable linker, such as but is not limited to a peptide linker, a Poly(ethylene glycol) (PEG) linker, a streptavidin-biotin or avidin-biotin linker, or a combination thereof. In preferred embodiments of the invention, the first and second antigen recognition portions are conjugated by site-specific linkage. The linkage can be covalent bond(s) and/or non-covalent bonds, such as but is not limited to hydrogen bond(s).

The bispecific molecule of the invention can contain a single second antigen recognition portion conjugated to the first antigen recognition portion. Alternatively, the bispecific molecule of the invention can also contain two or more second antigen recognition portions conjugated to different regions of the first antigen recognition portion. For example, the bispecific molecule can contain two second antigen recognition portions conjugated to each of the heavy chains of a first antigen recognition monoclonal antibody. When two or more second antigen recognition portions are contained in the bispecific molecule, such second antigen recognition portions can be the same or different antigen recognition portions. The first and second second antigen recognition portions can be different antigen recognition portions that target the same antigen to be cleared. In a preferred embodiment of the invention, the first and second second antigen recognition portions target an antigenic molecule to be cleared cooperatively. As a non-limiting example, one of the second antigen recognition portions may enhance the binding of the other second antigen recognition portion to a pathogenic antigenic molecule, thereby facilitating the removal of the pathogenic antigenic

molecule. The first and second second antigen recognition portions can also be different antigen recognition portions that target different pathogenic antigenic molecules to be cleared.

5       The present invention makes use of various split inteins for the production of bispecific molecules. In one aspect of the invention, naturally occurring split inteins are used for the production of bispecific molecules. In another aspect of the invention, engineered split intein based on naturally  
10 occurring non-split inteins are used for the production of bispecific molecules. In various embodiments of the invention, a split intein can be modified by adding, deleting, and/or mutating one or more amino acid residues to the N-intein and/or the C-intein such that the modification  
15 improves or enhances the intein's proficiency in trans-splicing and/or permits control of trans-splicing processes. In one preferred embodiment, a Cys residue can be included at the carboxy terminus of a C-intein so that the requirement that the molecular moiety conjugated to the C-intein must  
20 start with a Cys is alleviated. In other preferred embodiments, one or more native proximal extein residues are added to the N- and/or C-intein to facilitate trans-splicing in a foreign extein content.

      In a preferred embodiment of the invention, the trans-splicing system of the split intein encoded in the DnaE gene  
25 of *Synechocystis* sp. PCC6803 is used. In another embodiment of the invention, an engineered split intein system based on the *Mycobacterium tuberculosis* RecA intein is used. The production of bispecific molecules can be carried out in vitro wherein the intein antigen recognition portion  
30 fragments are expressed in separate hosts. The production of bispecific molecules can also be carried out in vivo. In one embodiment, nucleic acids encoding the intein antigen recognition portion fragments are inserted into separate vectors which are then co-transfected into a host for in vivo  
35 production of the bispecific molecule. In another embodiment, nucleic acids encoding the intein fragments are

inserted into the same vector which is then transfected into a host for in vivo production of the bispecific molecule.

In the present invention, the N-intein first antigen recognition portion fragment is preferably produced by fusing  
5 an appropriate antigen recognition moiety that binds a C3b-like receptor to the N-terminus of the N-intein of a suitable split intein. In a preferred embodiment, the C-terminus of the heavy chain of an anti-CR1 mAb is fused to the N-terminus of the N-intein of a split intein.

10 In the present invention, the C-intein second antigen recognition portion fragment is preferably produced by fusing an appropriate antigen recognition moiety that binds a pathogenic antigenic molecule to be cleared to the C-terminus of the C-intein of a suitable split intein. The amino acid  
15 residue immediately at the C-terminal side of the splice junction of the C-intein is a cysteine, serine, or threonine. In another embodiment of the invention, a C-intein streptavidin is produced by fusing a streptavidin to the C-terminus of a C-intein comprising a Cys, Ser, or Thr  
20 immediately downstream of the splice junction and is used in trans-splicing to produce a first antigen recognition portion-streptavidin fusion molecule which subsequently reacts with a biotinylated second antigen recognition portion to produce the bispecific molecule. It is also understood  
25 that other molecules that specifically bind biotin, including but not limited to avidin, are also within the scope of the present invention.

In one embodiment of the present invention, the bispecific molecule is produced by mixing the N-intein first antigen recognition portion fragment and the C-intein second  
30 antigen recognition portion fragment in vitro so that the fragments reconstitute and undergo trans-splicing. In another embodiment of the invention, a first antigen recognition portion-streptavidin molecule is produced by mixing the N-intein first antigen recognition portion  
35 fragment and the C-intein streptavidin fragment in vitro to produce a first antigen recognition portion-streptavidin

molecule. The bispecific molecule is then produced by reaction of the first antigen recognition-streptavidin molecule with a biotinylated second antigen recognition portion. It is also understood that other molecules that specifically bind biotin, such as but is not limited to  
5 avidin, are also within the scope of the present invention.

The present invention also relates to the production of polyclonal libraries of bispecific molecules. In one embodiment of the invention, a library of bispecific  
10 molecules that target multiple epitopes of a pathogenic antigenic molecule is produced using trans-splicing for conjugating each member of a population of second antigen recognition portions, such as those selected from a sufficiently large phage display library, to an anti-CR1  
15 monoclonal antibody (mAb). In a preferred embodiment, the polyclonal library is produced without clonal separation of individual members from the population of selected second antigen recognition portions. Polyclonal libraries of bispecific molecules that target multiple variants of a  
20 pathogenic antigenic molecule are also envisioned. In another embodiment of the invention, the polyclonal library of bispecific molecules is produced using the streptavidin-biotin configuration of the present invention. In still another embodiment of the invention, a plurality of N-intein anti-CR1 mAb fragments comprising a plurality of different  
25 anti-CR1 mAbs that target different sites on the red blood cells are mixed with the plurality of C-intein antigen recognition portion fragments with a plurality of specificities to produce a polyclonal library of bispecific molecules having polyclonal first and second antigen  
30 recognition portions.

The present invention also provides nucleic acids encoding the bispecific molecules of the invention as well as intermediate molecules of the invention.

The present invention also provides cells that contain  
35 the bispecific molecules and cells that are transformed by vectors encoding intermediate molecules.

The present invention also provides kits containing the intein antigen recognition portion fragments of the invention, or one or more nucleic acids encoding the intein antigen recognition portion fragments of the invention, or  
5 cells transformed with such nucleic acids, in one or more containers. Such kits can be used to practice the present invention.

The present invention further provides methods for using the bispecific molecules in the treatment of various  
10 disorders.

#### 4. BRIEF DESCRIPTION OF FIGURES

Figures 1a-1e illustrate some preferred embodiments of the bispecific molecules of the present invention. Fig. 1a:  
15 schematic illustration of N-intein anti-CR1 fragment; Fig. 1b: schematic illustration of C-intein pathogen binding moiety fragment; Fig. 1c: schematic illustration of C-intein streptavidin fragment; Fig. 1d: schematic illustration of some configurations of bispecific molecules; Fig. 1e:  
20 schematic illustration of some configurations of bispecific molecules including a streptavidin-biotin linker.

Figure 2 illustrates process of producing bispecific molecules using protein trans-splicing.

Figure 3a-3d illustrate the amino acid sequence of the naturally occurring split intein encoded in the DnaE gene of  
25 Ssp (Wu et al., 1998, Proc. Natl. Acad. Sci. USA 95:9226-9231). Fig. 3a: amino acid sequence of the N-intein (SEQ ID NO:1); Fig. 3b: amino acid sequence of the C-intein, including the immediate downstream cysteine (SEQ ID NO:2);  
Fig. 3c: amino acid sequence of the first ten N-extein  
30 residues (SEQ ID NO:3); Fig. 3d: amino acid sequence of the first ten C-extein residues (SEQ ID NO:4).

#### 5. DETAILED DESCRIPTION OF THE INVENTION

The present invention provides methods utilizing protein  
35 trans-splicing for producing bispecific molecules that bind both a C3b-like receptor, or its functional equivalent, and



an antigenic molecule to be cleared from the circulation. The N- and C-intein from a split intein system are linked to a C3b-like receptor recognition portion and an antigen recognition portion respectively. Subsequent reconstitution and trans-splicing reactions ligate the two antigen recognition portions and produce a bispecific molecule. The method for producing bispecific molecules using protein trans-splicing is site-specific, permitting the design and construction of bispecific molecules with particular structure and function(s). The invention also relates to methods of utilizing protein trans-splicing to ligate a C3b-like receptor recognition portion with an antigen recognition portion through a streptavidin-biotin or avidin-biotin linker. Although hereinafter, streptavidin is referred, it is understood that avidin can be used in place of streptavidin and therefore is within the scope of the present invention. In this configuration of the invention, rather than being directly linked to an antigen recognition portion, the C-intein is linked to a streptavidin. Streptavidin has been given to humans without eliciting an immunological response (Li et al., 1999, Protein Engineering 12:787-796; Rusckowski et al., 1996, J. Nucl. Med. 37:1655-1662; Samuel et al., 1996, J. Nucl. Med. 37:55-61). Reconstitution and trans-splicing produce a molecule consisting of a C3b-like receptor recognition portion ligated to a streptavidin. This molecule can then be conjugated with an antigen recognition portion by reacting with a biotinylated antigen recognition portion. This configuration of the invention is particularly useful in producing bispecific molecules that comprises a monoclonal antibody (mAb) as the antigen recognition portion. This configuration of the invention is also particularly useful in producing bispecific molecules wherein the antigen recognition portion is a non-proteinaceous moiety, such as a nucleic acid or an organic small molecule. The invention further relates to methods of producing polyclonal libraries of bispecific molecules using protein trans-splicing.

A bispecific molecule generally refers to a molecule having two or more different antigen recognition specificities. The bispecific molecule of the present invention refers to a molecule having a first antigen  
5 recognition portion that binds a C3b-like receptor, such as the type 1 complement receptor in primates, and a second antigen recognition portion that binds a pathogenic antigenic molecule. The pathogenic antigenic molecule is desired to be cleared from the circulation. The first and second antigen  
10 recognition portions are linked by sufficiently strong linkage such that the first and second antigen recognition portions form a stable association, preferably the linkage is site-specific to one or both antigen recognition portions. In a preferred configuration, the first and second antigen  
15 recognition portions are linked by a peptide bond. The first and second antigen recognition portions can also be linked through a spacer or linker, such as but is not limited to a peptide linker, a Poly(ethylene glycol) (PEG) linker, or a streptavidin-biotin linker.

As used herein, the term "antigen recognition portion"  
20 refers to a molecular moiety that recognizes and binds an antigenic molecule or, alternatively, is recognized and bound by an antigenic molecule. The molecular moiety can contain antigen binding domain(s) and effector domain(s). An  
25 effector domain refers to a portion of the molecular moiety that facilitates the transfer of the blood cell-immune complex, such as the erythrocyte-immune complex in primate, to an acceptor cell for proteolysis. For example, an effector domain can comprise an Fc domain of an mAb, i.e., a hinge region, a CH2 domain and a CH3 domain of a heavy chain.  
30 Alternatively, an effector domain can comprise an Fc domain with the CH2 domain and the CH3 domain in reverse order, i.e., the CH3 domain appears at the amino terminal side of the CH2 domain.

As used herein, the term "molecular moiety" encompasses  
35 any molecule or fragment thereof, including but are not limited to peptides and polypeptides, nucleic acids,

oligosaccharide, organic small molecules, and any combination thereof.

As used herein, the term "site-specific linkage" encompasses any linkage that connects two molecular moieties at defined site(s). The linkage can be formed by a covalent bond, such as but is not limited to a covalent peptide bond. The linkage can also be formed by other type of bond(s), such as but are not limited to hydrogen bond(s).

As used herein, the term "C3b-like receptor" refers to any mammalian circulatory molecule expressed on the surface of a mammalian blood cell, which has an analogous function to a primate C3b receptor, the CR1, in that it binds to a molecule associated with an immune complex, which is then chaperoned by the blood cell to a phagocytic cell for clearance. A mammalian blood cell can be, but is not limited to, a primate red-blood cell or erythrocyte.

As used herein, the term "protein trans-splicing" refers to protein splicing reactions that involve split intein systems. A split intein system refers to any intein system wherein a peptide bond break exists between the amino terminal and carboxy terminal amino acid sequences such that the N-terminal and C-terminal sequences become separate molecules which can reassociate, or reconstitute, into a functional trans-splicing element. The split intein system can be a naturally occurring split intein system, which encompasses any split intein systems that exist in natural organisms. The split intein system can also be an engineered split intein system, which encompasses any split intein systems that are generated by separating a non-split intein into an N-intein and a C-intein by any standard methods known in the art. As a non-limiting example, an engineered split intein system can be generated by breaking a naturally occurring non-split intein into appropriate N- and C-terminal sequences. Preferably, such engineered intein systems comprise only the amino acid sequences essential for trans-splicing reactions.

As used herein, the term "N-terminal intein" or "N-intein" refers to any intein sequence that comprises the essential N-terminal amino acid sequences and that is functional for trans-splicing reactions. An "N-intein" thus  
5 also comprises a sequence that is spliced out when transplicing occurs. An N-intein can comprise a sequence that is a modification of a naturally occurring N-intein sequence. For example, an N-intein can comprise additional amino acid residues and/or mutated residues so long as the  
10 inclusion of such additional and/or mutated residues does not render the N-intein non-functional in trans-splicing. Preferably, the inclusion of the additional and/or mutated residues improves or enhances the N-intein's proficiency in trans-splicing and/or permits control of trans-splicing  
15 processes. In some embodiments of the invention, an "N-intein moiety" is used to refer to a molecule that comprises an N-intein and optionally a linker sequence; this linker sequence can be but is not limited to a peptide linker, a streptavidin-biotin linker, or a PEG linker, at the N-terminus of the N-intein. The terminus of an N-intein moiety  
20 is referred as the "N-terminal end" of the N-intein moiety, to which another molecule can be conjugated. When the linker is a peptide linker, the N-intein moiety is also referred to herein as an "N-intein peptide" and the "N-terminal end" is the N-terminus of the N-intein peptide.

25 As used herein, the term "C-terminal intein" or "C-intein" refers to any intein sequence that comprises the essential C-terminal amino acid sequences and that is functional for trans-splicing reactions. A "C-intein" thus also comprises a sequence that is spliced out when  
30 transplicing occurs. A C-intein can comprise a sequence that is a modification of a naturally occurring C-intein sequence. For example, a C-intein can comprise additional amino acid residues and/or mutated residues so long as the inclusion of such additional and/or mutated residues does not render the  
35 C-intein non-functional in trans-splicing. Preferably, the inclusion of the additional and/or mutated residues improves

or enhances the C-intein's proficiency in trans-splicing and/or permits control of trans-splicing processes. As a non-limiting example, a Cys residue can be included at the carboxy terminus of a C-intein so that the requirement that  
5 the molecular moiety conjugated to the C-intein must start with a Cys is alleviated. In some embodiments of the invention, a "C-intein moiety" is used to refer to a molecule that comprises a C-intein and optionally a linker sequence; this linker can be but is not limited to a peptide linker, a  
10 streptavidin-biotin linker, or a PEG linker, at the C-terminus of the C-intein. The terminus of a C-intein moiety is referred as the "C-terminal end" of the C-intein moiety, to which another molecule can be conjugated. When the linker is a peptide linker, the C-intein moiety is also referred to  
15 herein as a "C-intein peptide" and the "C-terminal end" is the C-terminus of the C-intein peptide.

As used herein, the term "N-terminal extein" or "N-extein" refers to any molecular moiety conjugated to the amino terminus of an N-intein.

20 As used herein, the term "C-terminal extein" or "C-extein" refers to any molecular moiety conjugated to the carboxy terminus of a C-intein.

As used herein, a polyclonal library of bispecific molecules of the present invention refers to a plurality of  
25 bispecific molecules each having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds an antigen to be cleared, the library comprising a plurality of second antigen recognition portions with a plurality of different specificities. Preferably, the plurality of bispecific molecules of the  
30 polyclonal library includes specificities for different epitopes of an antigenic molecule and/or for different variants of an antigenic molecule. More preferably, the plurality of bispecific molecules of the polyclonal population includes specificities for a substantial portion  
35 of naturally-occurring variants of an antigenic molecule. The polyclonal library can also include specificities for a

mixture of different antigenic molecules. In preferred  
embodiments, at least 90%, 75%, 50%, 20%, 10%, 5%, or 1% of  
bispecific molecules in the polyclonal population target the  
desired antigenic molecule and/or antigenic molecules. In  
5 other preferred embodiments, the proportion of any single  
bispecific molecule in the polyclonal population does not  
exceed 90%, 50%, or 10% of the population. The polyclonal  
library comprises at least 2 different bispecific molecules  
with different specificities. More preferably, the  
10 polyclonal library comprises at least 10 different bispecific  
molecules with different specificities. Most preferably, the  
polyclonal library comprises at least 100 different  
bispecific molecules with different specificities.

As used herein, a cocktail of bispecific molecules of  
15 the present invention refers to a mixture of purified  
bispecific molecules blended together for targeting one or a  
mixture of antigens. In particular, the cocktail of  
bispecific molecules refers to a mixture of purified  
bispecific molecules having a plurality of second antigen  
20 recognition portions that target different or same antigenic  
molecules and that are of mixed types. For example, the  
mixture of the second antigen recognition portions can be a  
mixture of peptides, nucleic acids, and/or organic small  
molecules. A cocktail of bispecific molecules can generally  
be prepared by mixing various purified bispecific molecules.

25 Section 5.1. below describes the bispecific molecules of  
the present invention. Section 5.2. describes protein trans-  
splicing systems that can be used in the present invention.  
Split inteins and methods for their production are described  
in the section. Section 5.3. describes the production and  
30 purification of bispecific molecules using protein trans-  
splicing. Procedures for the preparation of intein  
fragments, methods for the production of bispecific molecules  
using such intein fragments in vitro and in vivo, and methods  
for the purification and characterization of bispecific  
35 molecules are described in this section in detail. Section  
5.4. describes the production of polyclonal libraries of

bispecific molecules using protein trans-splicing. Section 5.5. describes methods of using the bispecific molecules of the invention in the treatment of various diseases. Section 5.6. describes kits of materials that can be used to practice  
5 the invention. Section 5.7. describes applications of the methods of the present invention in the production of other bispecific molecules.

#### 5.1. BISPECIFIC MOLECULES

10 In the present invention, the first antigen recognition portion of the bispecific molecule can be any polypeptide that contains a CR1 binding domain and an effector domain. In a preferred embodiment, the first antigen recognition  
15 antigen recognition portion is an anti-CR1 polypeptide antibody, including but is not limited to, a single-chain variable region fragment (scFv) with specificity for a C3b-like receptor fused to the N-terminus of an immunoglobulin Fc domain. The first antigen binding portion can also be a  
20 chimeric antibody, such as but is not limited to a humanized monoclonal antibody wherein the complementarity determining regions are mouse, and the framework regions are human thereby decreasing the likelihood of an immune response in human patients treated with the antibody (United States  
25 Patent Nos. 4,816,567, 4,816,397, 5,693,762; 5,585,089; 5,565,332 and 5,821,337 which are incorporated herein by reference in their entirety). Preferably, the Fc domain of the chimeric antibody can be recognized by the Fc receptors on phagocytic cells, thereby facilitating the transfer and  
30 subsequent proteolysis of the RBC-immune complex. Although, for simplicity, this disclosure often makes references to an anti-CR1 antigen recognition portion or an anti-CR1 antibody, it is understood that such antigen recognition portion or antibody refers to an antigen recognition portion or antibody that binds any C3b-like receptor.

35 In the present invention, the second antigen recognition portion of the bispecific molecule can be any molecular

moiety, including but are not limited to any antibody or antigen binding fragments thereof, that recognizes and binds a pathogenic antigenic molecule. For example, the second antigen recognition portion can be an epitope or antigenic  
5 determinant that is bound by an antibody to be cleared from the circulatory system, such as that responsible for an autoimmune disease.

As used herein, "epitope" refers to an antigenic determinant, i.e., a region of a molecule that provokes an  
10 immunological response in a host or is bound by an antibody. This region can but need not comprise consecutive amino acids. The term epitope is also known in the art as "antigenic determinant." An epitope may comprise as few as three amino acids in a spatial conformation which is unique  
15 to the immune system of the host. Generally, an epitope consists of at least five such amino acids, and more usually consists of at least 8-10 such amino acids. Methods for determining the spatial conformation of such amino acids are known in the art.

The second antigen recognition portion of the  
20 bispecific molecule can also be a non-proteinaceous moiety. In one embodiment, the second antigen recognition portion is a nucleic acid. In another embodiment, the second antigen recognition portion is an organic small molecule. In still another embodiment, the second antigen binding portion is an  
25 oligosaccharide.

In preferred embodiments of the invention, the bispecific molecule comprises an anti-CR1 mAb and two second antigen recognition portions: a first, second antigen  
30 recognition portion fused to the C-terminus of a first heavy chain of the anti-CR1 mAb and a second, second antigen recognition portion fused to the C-terminus of a second heavy chain of the anti-CR1 mAb. In some embodiments, the two second antigen recognition portions are the same antigen  
35 recognition portions. In other embodiments, the two second antigen recognition portions are different antigen recognition portions. The two second antigen recognition



portions can be different antigen recognition portions that target the same antigenic molecule to be cleared. In a preferred embodiment of the invention, the two second antigen recognition portions target an antigenic molecule to be  
5 cleared cooperatively. As a non-limiting example, one of the second antigen recognition portions induces conformation alterations of the antigenic molecule so as to enhance the binding affinity of the other second antigen recognition portion, thereby facilitating the removal of the antigenic  
10 molecule (Thali et al., J. Acquired Immune Deficiency Syndromes 5:591-599). The two second antigen recognition portions can also be different antigen recognition portions that target different antigens to be cleared. The second antigen recognition portion can be, but is not limited to, an  
15 antigen binding domain, an epitope, a nucleic acid, or an organic small molecule.

In other preferred embodiments of the invention, the bispecific molecule comprises an anti-CR1 mAb and two second antigen recognition portions: a first, second antigen  
20 recognition portion fused to the C-terminus of a first light chain of the anti-CR1 mAb and a second, second antigen recognition portion fused to the C-terminus of a second light chain of the anti-CR1 mAb. In some embodiments, the two second antigen recognition portions are the same antigen recognition portions. In other embodiments, the two second  
25 antigen recognition portions are different antigen recognition portions. The two second antigen recognition portions can be different antigen recognition portions that target the same antigenic molecule to be cleared. In a preferred embodiment of the invention, the two second antigen  
30 recognition portions target an antigenic molecule to be cleared cooperatively. As a non-limiting example, one of the second antigen recognition portions may induce conformation alterations of the antigenic molecule so as to enhance the binding of the other second antigen recognition portion,  
35 thereby facilitating the removal of the antigenic molecule (Thali et al., J. Acquired Immune Deficiency Syndromes 5:591-

599). The two second antigen recognition portions can also be different antigen recognition portions that target different antigens to be cleared. The second antigen recognition portion can be, but is not limited to, an antigen binding domain, an epitope, a nucleic acid, or an organic small molecule.

Although in preferred embodiments of the invention, the second antigen recognition portion(s) is conjugated to either the heavy or the light chains of an anti-CR1 mAb, it is understood that other configurations are also encompassed by the invention. Non-limiting examples include but are not limited to configurations in which one second antigen recognition portion conjugates to a heavy chain and another second antigen recognition portion conjugates to a light chain. Configurations comprising more than two second antigen recognition portions conjugated to one anti-CR1 mAb are also envisioned.

In another embodiment of the invention, the bispecific molecule comprises an anti-CR1 mAb and an antigen recognition portion fused to the C-terminus of one of the heavy chains of the anti-CR1 mAb. In still another embodiment of the invention, the bispecific molecule comprises an anti-CR1 mAb and an antigen recognition domain fused to the C-terminus of one of the light chains of the anti-CR1 mAb. In still another embodiment of the invention, the bispecific molecule comprises an anti-CR1 polypeptide antibody, including but is not limited to, a scFv with specificity for a C3b-like receptor fused to the N-terminus of an immunoglobulin Fc domain, and an antigen recognition domain fused to the C-terminus of the anti-CR1 polypeptide. The antigen recognition domain can be, but is not limited to, an antigen binding domain, an epitope, a nucleic acid, or an organic small molecule.

It is understood that, in any embodiments described supra, the first and second antigen recognition portions can also be linked via a linker. In a preferred embodiment of the invention, the first and second antigen recognition

portions are linked by a peptide linker. In other preferred embodiments, the first and second antigen recognition portions are linked via a streptavidin-biotin or a PEG linker.

5

## 5.2. PROTEIN TRANS-SPLICING SYSTEM

The present invention contemplates a method of utilizing protein trans-splicing for the production of bispecific molecules. The method can be used to directly or via a  
10 linker conjugate a first antigen recognition portion, including but is not limited to an anti-CR1 mAb, with a second antigen recognition portion, including but is not limited to a peptide or polypeptide, a nucleic acid, and an organic small molecule, to form a bispecific molecule.  
15 Alternatively, the method can be used to conjugate a first antigen recognition portion with streptavidin to form a first antigen recognition portion-streptavidin fusion molecule which can be conjugated with a biotinylated second antigen recognition portion.

20 In the present invention, the N-terminus of an N-intein of a split intein is fused to a C-terminus of a C3b-like receptor recognition portion, such as but is not limited to an anti-CR1 mAb, whereas the C-terminus of a corresponding C-intein is conjugated with an antigen recognition portion.  
25 Any proteinaceous and non-proteinaceous antigen recognition moieties can be conjugated to the C-intein either directly or via a linker, such as but is not limited to a peptide linker, a streptavidin-biotin linker, or a PEG linker. The N-intein anti-CR1 mAb and the C-intein antigen recognition portion can then undergo reconstitution and trans-splicing whereby the  
30 C3b-like receptor recognition portion and the antigen recognition portion are ligated to form a bispecific molecule. Any split intein systems, including but is not limited to the naturally occurring split intein system based on the DnaE gene of *Synechocystis* sp. PCC6803, can be used in  
35 the present invention. Naturally occurring non-split intein systems, such as but is not limited to the *Mycobacterium*

tuberculosis RecA intein may also be used. When such intein systems that are not split intein systems in their native state are to be used, engineered split inteins can be obtained by separating a non-split intein into an N-intein  
5 and a C-intein by any standard molecular biological methods known in the art. Preferably, such engineered split inteins are constructed such that each of the N- and C-inteins comprises only the amino acid sequence essential for trans-splicing reaction. For example, any homing endonuclease  
10 sequence within a naturally occurring non-split intein can be removed without affecting the capability of the resultant split intein for trans-splicing reaction. The sequences that are to be included in an engineered split intein will be apparent to one skilled in the art.

15

#### 5.2.1. TRANS-SPLICING SYSTEM BASED ON NATURALLY OCCURRING SPLIT INTEINS

In one embodiment of the present invention, naturally occurring split inteins are used in the production of bispecific molecules of the invention. In a preferred  
20 embodiment, the trans-splicing system of the split intein encoded in the DnaE gene of *Synechocystis* sp. PCC6803 is used. The Ssp DnaE intein comprises a 123-amino acid N-terminal intein sequence (the Ssp 123 aa N-intein) and a 36-amino acid C-terminal intein sequence (the Ssp 36 aa C-  
25 intein). The nucleic acid sequences encoding the Ssp 123 aa N-intein and the Ssp 36 aa C-intein are displayed in Fig. 3.

In one embodiment, the Ssp 123 aa N-intein is used to prepare the N-intein first antigen recognition portion fragment, i.e., the N-intein anti-CR1. The N-terminus of the  
30 Ssp 123 aa N-intein is fused to the C-terminus of a C3b-like receptor recognition portion, such as but is not limited to an anti-CR1 mAb.

In another embodiment, the Ssp 36 aa C-intein is used to prepared the C-intein second antigen recognition portion fragment. The C-terminus of the Ssp 36 aa C-intein is  
35 conjugated with an antigen recognition portion having a Cys, Ser, or Thr at its N-terminus.

In another embodiment of the present invention, a 37 aa C-intein which adds a Cys, Ser, or Thr residue to the C-terminus of the Ssp 36 aa C-intein is used to prepare the C-intein second antigen recognition portion fragment.<sup>9</sup> This 37  
5 aa C-intein can be conjugated with any antigen recognition moiety, both proteinaceous and non-proteinaceous.

In still another embodiment of the present invention, one or more native proximal N-extein residues are added to the N-terminus of the Ssp 123 aa N-intein to form an N-intein  
10 of the invention. As used herein, "native proximal N-extein residues" refers to amino acid residues immediately upstream, i.e., at the amino terminal side, to the splice junction and having sequence identical to that in the native N-extein. In a preferred embodiment, 2 or more native proximal N-extein  
15 residues are added to the Ssp 123 aa N-intein. Such N-intein is then used to prepare the N-intein first antigen recognition portion fragment.

In still another embodiment of the present invention, one or more native proximal C-extein residues are added to the C-terminus of the Ssp 36 aa C-intein to form a C-intein  
20 of the invention. As used herein, "native proximal C-extein residues" refers to amino acid residues immediately downstream, i.e., at the carboxy terminal side, to the splice junction having sequence identical to that in the native C-extein. In a preferred embodiment, 3 or more native proximal  
25 C-extein residues are added to the Ssp 36 aa C-intein. Such C-intein is then used to prepare C-intein antigen recognition portion fragment.

In another embodiment, unnatural amino acid residues, such as but is not limited to an amino acid residue  
30 containing a caged photoreactive group, such as O-(2-nitrobenzyl)serine, can be incorporated at the N-terminus of an N-intein by site-directed mutagenesis so that splicing reactions can be activated by irradiation of light of an appropriate wavelength, preferably a wavelength in the range  
35 of 300-350nm. Other intein systems that permit controllable trans-splicing can also be designed by known methods in the

art and are considered to be within the scope of the invention.

Nucleic acids encoding the Ssp 123 aa N-intein and any of the modified Ssp N-inteins can be produced by standard methods known in the art. In one embodiment, the nucleic acids encoding an Ssp N-intein is synthesized by annealing a set of oligonucleotides comprising nucleotide sequences that span the nucleotide sequence of the desired N-intein. In another embodiment, the nucleic acids encoding an N-intein can be produced by amplification from an appropriate plasmid, such as but is not limited to the plasmid pDnaE-C-209, with appropriate primers, see Evans et al., 2000, J. Biol. Chem. 275:9091-9094. The nucleic acids encoding an N-intein can then be used in the construction of expression vectors.

Nucleic acids encoding the Ssp 36 aa C-intein and any of the modified Ssp C-intein can be produced by standard methods known in the art. In one embodiment, the nucleic acids encoding an Ssp C-intein is synthesized by annealing a set of oligonucleotides comprising nucleotide sequences that span the nucleotide sequence of the desired C-intein. In another embodiment, the nucleic acids encoding an C-intein can be produced by amplification from an appropriate plasmid by any standard method known in the art. The nucleic acids encoding a C-intein can then be used in the construction of expression vectors.

Alternatively, the Ssp N-inteins and C-inteins can be produced by peptide synthesis techniques. Any peptide synthesis techniques can be used for this purpose. It will be recognized by one skilled in the art that a multi-step peptide synthesis can be used for the synthesis of N-inteins. The synthesized N- and C-intein can then be chemically conjugated with antigen recognition portions by any methods known in the art.

#### 5.2.2. TRANS-SPLICING SYSTEM BASED ON ENGINEERED SPLIT INTEINS

In another embodiment of the present invention, the trans-splicing system of engineered split inteins are used in

the production of bispecific molecules of the invention. Examples of engineered split intein systems include but is not limited to that based on the Mtu RecA intein. An engineered Mtu RecA intein can comprise an N-terminal intein  
5 sequence of 105 amino acids (Mtu 105 aa N-intein) and a C-terminal intein sequence of 35 amino acid (Mtu 35 aa C-intein). The nucleic acid sequences encoding the Mtu N-intein and the Mtu C-intein can be found in the sequence of Mtu RecA gene (e.g., Accession No. X58485; Perler et al.,  
10 1997, Nucl. Acids Res. 25:1087-1093; Davis et al., 1992, Cell 71:201-210; Davis et al., 1991, J. Bacteriol. 173:5653-5662).

In one embodiment, the Mtu 105 aa N-intein is used to prepare the N-intein first antigen recognition portion fragment. The N-terminus of the Mtu 105 aa N-intein is fused  
15 to the C-terminus of a C3b-like receptor recognition portion, such as but is not limited to an anti-CR1 mAb.

In another embodiment, the Mtu 35 aa C-intein is used to prepare the C-intein second antigen recognition portion fragment. The C-terminus of the Mtu 35 aa C-intein is  
20 conjugated with an antigen recognition portion having a Cys at its N-terminus.

In another embodiment of the present invention, a 36 aa C-intein which adds a Cys, Ser, or Thr residue to the C-terminus of the Mtu 35 aa C-intein is used to prepared the C-intein second antigen recognition portion fragment. This 36  
25 aa C-intein can then be conjugated with any antigen recognition moiety, both proteinaceous and non-proteinaceous.

In still another embodiment of the present invention, one or more native proximal N-extein residues are added to the N-terminus of the Mtu 105 aa N-intein to form an N-intein  
30 of the invention. In a preferred embodiment, 2 or more native proximal N-extein residues are added to the Mtu 105 aa N-intein. Such N-intein is then used to prepare the N-intein antigen recognition portion fragment.

In still another embodiment of the present invention,  
35 one or more native proximal C-extein residues are added to the C-terminus of the Mtu 35 aa C-intein to form a C-intein

of the invention. In a preferred embodiment, 3 or more native proximal C-extein residues are added to the Mtu 35 aa C-intein. Such C-intein is then used to prepare C-intein antigen recognition portion fragment.

5 In still other embodiments, C-inteins comprising 36 to 52 amino acid residues are used to prepare the C-intein second antigen recognition portion fragment. The C-terminus of such a C-intein is conjugated with an antigen recognition portion having a Cys at its N-terminus. Alternatively, C-  
10 inteins comprising 36 to 52 amino acid residues plus a Cys, Ser, or Thr at the C-terminus can be used to prepare the C-intein second antigen recognition portion fragment.

In another embodiment, unnatural amino acid residues, such as but is not limited to an amino acid residue  
15 containing a caged photoreactive group, such as O-(2-nitrobenzyl)serine, can be incorporated at the N-terminus of an N-intein by site-directed mutagenesis so that splicing reactions can be activated by irradiation of light of an appropriate wavelength, preferably a wavelength in the range  
20 of 300-350nm. Other intein systems that permit controllable trans-splicing can also be designed by various known methods in the art and are considered to be within the scope of the invention.

Nucleic acids encoding the Mtu 105 aa N-intein and any of the modified Mtu N-inteins can be produced by standard  
25 methods known in the art. In one embodiment, the nucleic acids encoding an Mtu N-intein is synthesized by annealing a set of oligonucleotides comprising nucleotide sequences that span the nucleotide sequence of the desired N-intein. In another embodiment, the nucleic acids encoding an N-intein  
30 can be produced by amplification from an appropriate plasmid, such as but is not limited to the plasmid pMU1B (see Mills et al., 1998, Proc. Natl. Acad. Sci. USA 95:3543-3548). The nucleic acids encoding an N-intein can then be used in the construction of expression vectors.

35 Nucleic acids encoding the Mtu 35 aa C-intein and any of the modified Mtu C-intein can be produced by standard methods



known in the art. In one embodiment, the nucleic acids encoding an Mtu C-intein is synthesized by annealing a set of oligonucleotides comprising nucleotide sequences that span the nucleotide sequence of the desired C-intein. In another  
5 embodiment, the nucleic acids encoding a C-intein can be produced by amplification from an appropriate plasmid by standard methods known in the art. The nucleic acids encoding an C-intein can then be used in the construction of expression vectors.

10 Alternatively, the Mtu N-inteins and C-inteins can be produced by peptide synthesis techniques. Any peptide synthesis techniques can be used for this purpose. It will be recognized by one skilled in the art that a multi-step peptide synthesis can be used for the synthesis of N-inteins.  
15 The synthesized N- and C-intein can then be chemically conjugated with antigen recognition portions by any methods known in the art.

### 5.3. PRODUCTION AND PURIFICATION OF BISPECIFIC MOLECULES

20 The N-intein anti-CR1 fragment and the C-intein antigen recognition portion fragment are produced by fusing appropriate N-intein and C-intein (Section 5.2) with an anti-CR1 and an antigen recognition portion, respectively. The bispecific molecule is then produced by contacting the N-intein anti-CR1 fragment and the C-intein antigen recognition  
25 fragment under conditions such that protein trans-splicing occurs. As used herein, "contacting" refers to the placing or mixing of two or more reactant molecules in a reaction buffer, e.g., in a liquid solution, such that the two or more reactant molecules can encounter and react.  
30

#### 5.3.1. PRODUCTION AND PURIFICATION OF N-INTEIN FRAGMENT

The N-intein anti-CR1 fragment can be produced by conjugating an anti-CR1 with an appropriate N-intein, such as that described in Section 5.2. The N-intein anti-CR1  
35 fragment is preferably produced recombinantly. The N-intein anti-CR1 fragment is then used with an appropriate C-intein

antigen recognition portion fragment in a trans-splicing reaction for producing the bispecific molecule.

5                    **5.3.1.1. PRODUCTION OF ANTI-CR1 PORTION**

In preferred embodiments, the anti-CR1 portion of the bispecific molecule comprises an anti-CR1 mAb. An anti-CR1 mAb that binds a human C3b receptor can be produced by known methods. In one embodiment, an anti-CR1 mAb, preferably an anti-CR1 IgG, can be prepared using standard hybridoma procedures known in the art (see, for example, Kohler and Milstein, 1975, Nature 256:495-497; Hogg et al., 1984, Eur. J. Immunol. 14:236-243; O'Shea et al., 1985, J. Immunol. 134:2580-2587; Schreiber, U.S. Patent 4,672,044). A suitable mice is immunized with human CR1 which can be purified from human erythrocytes. The spleen cells obtained from the immunized mice are fused with an immortal mouse myeloma cell line which results in a population of hybridoma cells, including a hybridoma that produces an anti-CR1 antibody. The hybridoma which produces the anti-CR1 antibody is then selected, or 'cloned', from the population of hybridomas using conventional techniques such as enzyme linked immunosorbent assays (ELISA). Hybridoma cell lines expressing anti-CR1 mAb can also be obtained from various sources, for example, the murine anti-CR1 mAb that binds human CR1 described in U.S. Patent 4,672,044 is available as hybridoma cell line ATCC HB 8592 from the American Type Culture Collection (ATCC). Other anti-CR1 mAbs can also be used in the present invention, see, e.g., Nickells et al., 1998, Clin. Exp. Immunol. 112:27-33.

30            Nucleic acids encoding the heavy and light chains of an anti-CR1 mAb, preferably an anti-CR1 IgG, can then be prepared from the hybridoma cell line by standard methods known in the art. As a non-limiting example, cDNAs encoding the heavy and light chains of the anti-CR1 IgG can be prepared by priming mRNA using appropriate primers, followed by PCR amplification using appropriate forward and reverse

primers. Any commercially available kits for cDNA synthesis can be used. The nucleic acids can then be used in the construction of expression vector(s).

In another embodiment, nucleic acids encoding anti-CR1  
5 scFv's are prepared according to standard methods known in the art. In another embodiment, nucleic acids encoding anti-CR1 chimeric antibodies are prepared according to standard methods known in the art (United States Patent Nos. 4,816,567, 4,816,397, 5,693,762; 5,585,089; 5,565,332 and  
10 5,821,337 which are incorporated herein by reference in their entirety). The nucleic acids can then be used in the construction of expression vector(s).

#### 5.3.1.2. PRODUCTION AND PURIFICATION OF N-INTEIN ANTI-CR1 FRAGMENT

15 In the present invention, an N-intein anti-CR1 fragment can be produced recombinantly, whereby the N-terminus of the nucleotide sequence encoding the N-intein is fused to the C-terminus of the immunoglobulin constant domain sequence. The fusion preferably is with the immunoglobulin heavy chain.  
20 However, the fusion with the immunoglobulin light chain is also envisioned. If desired, a nucleotide sequence encoding a suitable linker peptide can also be introduced between the nucleotide sequence encoding the N-intein and the nucleotide sequence encoding the anti-CR1 moiety.

25 In one embodiment, nucleotide sequence encoding the N-intein anti-CR1 heavy chain fragment and the immunoglobulin light chain are inserted into separate expression vectors, and are co-transfected into a suitable host. Non-limiting examples of hosts include E. coli, yeast, insect cell, and  
30 mammalian host systems, such as a Chinese hamster ovary cell line. A mammalian cell line is preferable for the expression of anti-CR1 mAb. Employing separate expression vectors provides for the ability to adjust the proportions of each of the two polypeptide fragments in unequal ratios of the two  
35 polypeptide chains, thus providing optimum yields. It is, however, possible to insert the coding sequences for the two polypeptide chains in one expression vector when the

expression of at least two polypeptide chains in equal ratios results in high yields or when the ratios are of no particular significance.

In other embodiments, the expression vectors are  
5 transfected separately into different hosts. The polypeptides are then mixed in vitro under conditions that allow formation of the multiunit antibody. In another embodiment, the N-intein anti-CR1 heavy chain or the N-intein anti-CR1 light chain is mixed with normal anti-CR1 heavy and  
10 light chains such that at least a portion of the multiunit antibodies are N-intein anti-CR1 fragment comprising one N-intein fused to one of the anti-CR1 heavy chain or anti-CR1 light chain. This embodiment is therefore useful for producing bispecific molecules comprising an anti-CR1 mAb and  
15 one antigen recognition portion fused to the C-terminus of one of the heavy chains or one of the light chains of the anti-CR1 mAb.

In still other embodiments, nucleotide sequence encoding the N-intein scFv fragment is inserted into an expression  
20 vector, and transfected into a suitable host. Non-limiting examples of hosts include E. coli, yeast, insect cell, and mammalian host systems, such as a Chinese hamster ovary cell line.

The N-intein anti-CR1 mAb fragment from antibody  
25 secreting cells can be purified by various methods known in the art. For example, the N-intein anti-CR1 mAb fragment can be purified by ion exchange chromatography. Non-limiting examples of columns suitable for isolation include DEAE, Hydroxylapatite, Calcium Phosphate (see generally Current  
30 Protocols in Immunology, 1994, John Wiley & Sons, Inc., New York, NY). The N-intein anti-CR1 mAb fragment can also be purified by affinity chromatography using a column made of protein A-Sepharose, followed by elution from the immunosorbant using an acid buffer. A column that utilizes C3b-like receptor can also be used. One skilled in the art  
35 will recognize that any method of purifying proteins using size or affinity will be suitable in the present invention.

### 5.3.2. PRODUCTION AND PURIFICATION OF C-INTEIN FRAGMENT

The C-intein antigen recognition portion fragment can be  
5 produced by conjugating an antigen recognition portion with  
an appropriate C-intein, such as that described in Section  
5.2. The C-intein antigen recognition portion fragment can  
be produced chemically or recombinantly. The C-intein  
antigen recognition portion fragment is then mixed with the  
10 appropriate N-intein anti-CR1 fragemnt in a trans-splicing  
reaction for producing bispecific molecules. Alternatively,  
a C-intein streptavidin fragment is prepared and mixed with  
the N-intein fragment in the trans-splicing reaction to  
produce an anti-CR1 streptavidin molecule, which is then used  
15 for producing a bispecific molecule by reacting with a  
biotinylated antigen recognition portion.

#### 5.3.2.1. PRODUCTION OF ANTIGEN RECOGNITION MOIETIES

The antigen recognition moiety of the bispecific  
molecule of the invention can be any molecular moiety that  
20 recognizes and binds an antigenic molecule, including but are  
not limited to any antibody or antigen binding fragments  
thereof, or any molecular moiety that is recognized and bound  
by a molecule to be cleared, including but is not limited to  
an epitope or antigenic determinant, a nucleic acid, and an  
25 organic small molecule. Such antigen recognition moieties  
can be produced by various methods known in the art. The  
antigen recognition moiety is then conjugated with C-intein  
for trans-splicing.

Antibodies can be prepared by immunizing a suitable  
30 subject with an antigen as an immunogen. The antibody titer  
in the immunized subject can be monitored over time by  
standard techniques, such as with an enzyme linked  
immunosorbent assay (ELISA) using immobilized polypeptide.  
If desired, the antibody molecules can be isolated from the  
35 mammal (e.g., from the blood) and further purified by well-

known techniques, such as protein A chromatography to obtain the IgG fraction.

At an appropriate time after immunization, e.g., when the specific antibody titers are highest, antibody-producing  
5 cells can be obtained from the subject and used to prepare monoclonal antibodies by standard techniques, such as the hybridoma technique originally described by Kohler and Milstein (1975, Nature 256:495-497), the human B cell hybridoma technique by Kozbor et al. (1983, Immunol. Today  
10 4:72), the EBV-hybridoma technique by Cole et al. (1985, Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, Inc., pp. 77-96) or trioma techniques. The technology for producing hybridomas is well known (see generally Current Protocols in Immunology, 1994, John Wiley & Sons, Inc., New  
15 York, NY). Hybridoma cells producing a monoclonal antibody of the invention are detected by screening the hybridoma culture supernatants for antibodies that bind the polypeptide of interest, e.g., using a standard ELISA assay.

Monoclonal antibodies are obtained from a population of substantially homogeneous antibodies, i.e., the individual  
20 antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Thus, the modifier "monoclonal" indicates the character of the antibody as not being a mixture of discrete antibodies. For example, the monoclonal antibodies may be  
25 made using the hybridoma method first described by Kohler et al., 1975, Nature, 256:495, or may be made by recombinant DNA methods (U.S. Pat. No. 4,816,567). The term "monoclonal antibody" as used herein also indicates that the antibody is an immunoglobulin.

30 In the hybridoma method of generating monoclonal antibodies, a mouse or other appropriate host animal, such as a hamster, is immunized as hereinabove described to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the protein used  
35 for immunization (see generally, U.S. Patent No. 5,914,112, which is incorporated herein by reference in its entirety.)

Alternatively, lymphocytes may be immunized in vitro. Lymphocytes then are fused with myeloma cells using a suitable fusing agent, such as polyethylene glycol, to form a hybridoma cell (Goding, Monoclonal Antibodies: Principles and Practice, pp. 59-103 (Academic Press, 1986)). The hybridoma cells thus prepared are seeded and grown in a suitable culture medium that preferably contains one or more substances that inhibit the growth or survival of the unfused, parental myeloma cells. For example, if the parental myeloma cells lack the enzyme hypoxanthine guanine phosphoribosyl transferase (HGPRT or HPRT), the culture medium for the hybridomas typically will include hypoxanthine, aminopterin, and thymidine (HAT medium), which substances prevent the growth of HGPRT-deficient cells.

Preferred myeloma cells are those that fuse efficiently, support stable high-level production of antibody by the selected antibody-producing cells, and are sensitive to a medium such as HAT medium. Among these, preferred myeloma cell lines are murine myeloma lines, such as those derived from MOPC-21 and MPC-11 mouse tumors available from the Salk Institute Cell Distribution Center, San Diego, Calif. USA, and SP-2 cells available from the American Type Culture Collection, Rockville, Md. USA.

Human myeloma and mouse-human heteromyeloma cell lines also have been described for the production of human monoclonal antibodies (Kozbor, 1984, J. Immunol., 133:3001; Brodeur et al., Monoclonal Antibody Production Techniques and Applications, pp. 51-63 (Marcel Dekker, Inc., New York, 1987)). Culture medium in which hybridoma cells are growing is assayed for production of monoclonal antibodies directed against the antigen. Preferably, the binding specificity of monoclonal antibodies produced by hybridoma cells is determined by immunoprecipitation or by an in vitro binding assay, such as radioimmunoassay (RIA) or enzyme-linked immuno-absorbent assay (ELISA). The binding affinity of the monoclonal antibody can, for example, be determined by the

Scatchard analysis of Munson et al., 1980, Anal. Biochem., 107:220.

After hybridoma cells are identified that produce antibodies of the desired specificity, affinity, and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods (Goding, Monoclonal Antibodies: Principles and Practice, pp. 59-103 (Academic Press, 1986)). Suitable culture media for this purpose include, for example, D-MEM or RPMI-1640 medium. In addition, the hybridoma cells may be grown in vivo as ascites tumors in an animal. The monoclonal antibodies secreted by the subclones are suitably separated from the culture medium, ascites fluid, or serum by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

Alternative to preparing monoclonal antibody-secreting hybridomas, a monoclonal antibody directed against a pathogen or pathogenic antigenic molecule polypeptide of the invention can be identified and isolated by screening a recombinant combinatorial immunoglobulin library (e.g., an antibody phage display library) with the antigen of interest. Kits for generating and screening phage display libraries are commercially available (e.g., Pharmacia Recombinant Phage Antibody System, Catalog No. 27-9400-01; and the Stratagene antigen SurfZAP™ Phage Display Kit, Catalog No. 240612). Additionally, examples of methods and reagents particularly amenable for use in generating and screening antibody display library can be found in, for example, U.S. Patent Nos. 5,223,409 and 5,514,548; PCT Publication No. WO 92/18619; PCT Publication No. WO 91/17271; PCT Publication No. WO 92/20791; PCT Publication No. WO 92/15679; PCT Publication No. WO 93/01288; PCT Publication No. WO 92/01047; PCT Publication No. WO 92/09690; PCT Publication No. WO 90/02809; Fuchs et al., 1991, Bio/Technology 9:1370-1372; Hay et al., 1992, Hum. Antibod. Hybridomas 3:81-85; Huse et al., 1989, Science 246:1275-1281; Griffiths et al., 1993, EMBO J. 12:725-734. A



phage display library permits selection of desired antibody or antibodies from a very large repertoire of specificities. An additional advantage of a phage display library is that the nucleic acids encoding the selected antibodies can be  
5 obtained conveniently, thereby facilitating subsequent construction of expression vectors.

In addition, techniques developed for the production of "chimeric antibodies" (Morrison et al., 1984, Proc. Natl. Acad. Sci., 81, 6851-6855; Neuberger et al., 1984, Nature  
10 312, 604-608; Takeda et al., 1985, Nature, 314, 452-454) by splicing the genes from a mouse antibody molecule of appropriate antigen specificity together with genes from a human antibody molecule of appropriate biological activity can be used. A chimeric antibody is a molecule in which  
15 different portions are derived from different animal species, such as those having a variable region derived from a murine mAb and a human immunoglobulin constant region. (See, e.g., Cabilly et al., U.S. Patent No. 4,816,567; and Boss et al., U.S. Patent No. 4,816,397, which are incorporated herein by  
20 reference in their entirety.)

Humanized antibodies are antibody molecules from non-human species having one or more complementarity determining regions (CDRs) from the non-human species and a framework region from a human immunoglobulin molecule. (see  
25 e.g., U.S. Patent No. 5,585,089, which is incorporated herein by reference in its entirety.) Such chimeric and humanized monoclonal antibodies can be produced by recombinant DNA techniques known in the art, for example using methods described in PCT Publication No. WO 87/02671; European Patent  
30 Application 184,187; European Patent Application 171,496; European Patent Application 173,494; PCT Publication No. WO 86/01533; U.S. Patent No. 4,816,567 and 5,225,539; European Patent Application 125,023; Better et al., 1988, Science 240:1041-1043; Liu et al., 1987, Proc. Natl. Acad. Sci. USA 84:3439-3443; Liu et al., 1987, J. Immunol. 139:3521-3526;  
35 Sun et al., 1987, Proc. Natl. Acad. Sci. USA 84:214-218; Nishimura et al., 1987, Canc. Res. 47:999-1005; Wood et al.,

1985, Nature 314:446-449; Shaw et al., 1988, J. Natl. Cancer  
Inst. 80:1553-1559; Morrison 1985, Science 229:1202-1207; Oi  
et al., 1986, Bio/Techniques 4:214; Jones et al., 1986,  
Nature 321:552-525; Verhoeyan et al., 1988, Science 239:1534;  
5 and Beidler et al., 1988, J. Immunol. 141:4053-4060.

Complementarity determining region (CDR) grafting is  
another method of humanizing antibodies. It involves  
reshaping murine antibodies in order to transfer full antigen  
specificity and binding affinity to a human framework (Winter  
10 et al. U.S. Patent No. 5,225,539). CDR-grafted antibodies  
have been successfully constructed against various antigens,  
for example, antibodies against IL-2 receptor as described in  
Queen et al., 1989 (Proc. Natl. Acad. Sci. USA 86:10029);  
antibodies against cell surface receptors-CAMPATH as  
15 described in Riechmann et al. (1988, Nature, 332:323);  
antibodies against hepatitis B in Cole et al. (1991, Proc.  
Natl. Acad. Sci. USA 88:2869); as well as against viral  
antigens-respiratory syncytial virus in Tempest et al. (1991,  
Bio-Technology 9:267). CDR-grafted antibodies are generated  
20 in which the CDRs of the murine monoclonal antibody are  
grafted into a human antibody. Following grafting, most  
antibodies benefit from additional amino acid changes in the  
framework region to maintain affinity, presumably because  
framework residues are necessary to maintain CDR  
25 conformation, and some framework residues have been  
demonstrated to be part of the antigen binding site.  
However, in order to preserve the framework region so as not  
to introduce any antigenic site, the sequence is compared  
with established germline sequences followed by computer  
modeling.

30 Completely human antibodies are particularly desirable  
for therapeutic treatment of human patients. Such antibodies  
can be produced using transgenic mice which are incapable of  
expressing endogenous immunoglobulin heavy and light chain  
genes, but which can express human heavy and light chain  
35 genes. The transgenic mice are immunized in the normal

procedure, e.g., determine the efficacy of a given treatment regimen. Detection can be facilitated by coupling the antibody to a detectable substance. Examples of detectable substances include various enzymes, prosthetic groups, fluorescent materials, luminescent materials, bioluminescent materials, and radioactive materials. Examples of suitable enzymes include horseradish peroxidase, alkaline phosphatase, beta-galactosidase, or acetylcholinesterase; examples of suitable prosthetic group complexes include streptavidin/biotin and avidin/biotin; examples of suitable fluorescent materials include umbelliferone, fluorescein, fluorescein isothiocyanate, rhodamine, dichlorotriazinylamine fluorescein, dansyl chloride or phycoerythrin; an example of a luminescent material includes luminol; examples of bioluminescent materials include luciferase, luciferin, and aequorin, and examples of suitable radioactive material include  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{35}\text{S}$  or  $^3\text{H}$ .

An antigenic fragment suitable for use as an antigenic recognition moiety comprises at least a portion of the antigen that is 8 amino acids, more preferably 10 amino acids and more preferably still, 15 amino acids long. Antigens and antigenic fragments used as antigen recognition moieties can be recombinantly expressed or chemically synthesized.

The invention also provides chimeric or fusion antigens for use as antigen recognition moieties. As used herein, a "chimeric antigen" or "fusion antigen" comprises all or part of an antigen for use in the invention, operably linked to a heterologous polypeptide. Within the fusion antigen, the term "operably linked" is intended to indicate that the antigen and the heterologous polypeptide are fused in-frame to each other. The heterologous polypeptide can be fused to the N-terminus or C-terminus of the antigen.

Chimeric and fusion proteins can be produced by standard recombinant DNA techniques. In one embodiment, the fusion gene can be synthesized by conventional techniques including automated DNA synthesizers. Alternatively, PCR amplification of gene fragments can be carried out using anchor primers

fashion with a selected antigen, e.g., all or a portion of an immunogen.

Monoclonal antibodies directed against the antigen can be obtained using conventional hybridoma technology. The human immunoglobulin transgenes harbored by the transgenic mice rearrange during B cell differentiation, and subsequently undergo class switching and somatic mutation. Thus, using such a technique, it is possible to produce therapeutically useful IgG, IgA and IgE antibodies. For an overview of this technology for producing human antibodies, see Lonberg and Huszar (1995, Int. Rev. Immunol. 13:65-93). For a detailed discussion of this technology for producing human antibodies and human monoclonal antibodies and protocols for producing such antibodies, see e.g., U.S. Patent 5,625,126; U.S. Patent 5,633,425; U.S. Patent 5,569,825; U.S. Patent 5,661,016; and U.S. Patent 5,545,806. In addition, companies such as Abgenix, Inc. (Freemont, CA (see, for example, U.S. Patent No. 5,985,615)) and Medarex, Inc. (Princeton, NJ), can be engaged to provide human antibodies directed against a selected antigen using technology similar to that described above.

Completely human antibodies which recognize and bind a selected epitope can be generated using a technique referred to as "guided selection." In this approach a selected non-human monoclonal antibody, e.g., a mouse antibody, is used to guide the selection of a completely human antibody recognizing the same epitope (Jespers et al. (1994) antigen Bio/technology 12:899-903).

A pre-existing antibody directed against a pathogen can be used to isolate additional antigens of the pathogen by standard techniques, such as affinity chromatography or immunoprecipitation for use as immunogens. Moreover, such an antibody can be used to detect the protein (e.g., in a cellular lysate or cell supernatant) in order to evaluate the abundance and pattern of expression of the pathogen. The antibodies can also be used diagnostically to monitor pathogen levels in tissue as part of a clinical testing

which give rise to complementary overhangs between two consecutive gene fragments which can subsequently be annealed and reamplified to generate a chimeric gene sequence (e.g., Ausubel et al., supra). Moreover, many expression vectors  
5 are commercially available that already encode a fusion domain (e.g., a GST polypeptide). A nucleic acid encoding an immunogen can be cloned into such an expression vector such that the fusion domain is linked in-frame to the polypeptide.

Other types of antigen recognition moiety can be  
10 produced using appropriate methods known in the art. For example, nucleic acids can be produced by any known DNA synthesis methods. Organic small molecules can be produced by organic synthesis.

15       **5.3.2.2. PRODUCTION AND PURIFICATION OF C-INTEIN  
          ANTIGEN RECOGNITION PORTION FRAGMENT**

In the present invention, a C-intein antigen recognition portion fragment is produced recombinantly, whereby the C-terminus of the nucleotide sequence encoding the C-intein is fused to the N-terminus of an antigen recognition moiety. If  
20 desired, a nucleotide sequence encoding a suitable linker peptide can also be introduced between the nucleotide sequence encoding the C-intein and the nucleotide sequence encoding the antigen recognition moiety.

In one embodiment, nucleotide sequence encoding a C-  
25 intein antigen recognition portion fragment is inserted into a suitable expression vector, and are transfected into a suitable host. Non-limiting example include E. coli, yeast, insect cell, and mammalian systems, such as a Chinese hamster ovary cell line.

30       The C-intein antigen recognition portion fragment from antibody secreting cells can be isolated by ion exchange chromatography. Non-limiting examples of columns suitable for purification of the bispecific antibodies of the invention include DEAE, Hydroxylapatite, Calcium Phosphate  
35 (see generally Current Protocols in Immunology, 1994, John Wiley & Sons, Inc., New York, NY). The C-intein antigen recognition portion fragment can also be purified by affinity

chromatography using a suitable column that uses the specific antigen. One skilled in the art will recognize that any method of purifying proteins using size or affinity will be suitable in the present invention.

5 A C-intein antigen recognition portion fragment can also be produced by chemically conjugating C-intein and the desired antigen recognition moiety. If desired, a suitable linker peptide, such as but is not limited to a peptide linker or a PEG linker, can also be introduced between the C-  
10 intein and the antigen recognition moiety.

A C-intein can also be conjugated with a streptavidin molecule. In one embodiment, a C-intein is conjugated with a streptavidin chemically by standard methods known in the art. For example, the streptavidin can be conjugated to the C-  
15 intein via a thioether linker (see, for example, Li et al., 1999, Protein Engineering 12:787-796).

In another embodiment, a C-intein is conjugated with streptavidin recombinantly. Nucleic acid encoding a C-intein is fused to the nucleic acid encoding the monomer of core streptavidin and inserted into an appropriate vector which  
20 can then be expressed in an appropriate host. It is known, however, that streptavidin can form tetramers and dimers (Ernst et al., 1999, Human Antibodies 9:165-170; Kipriyaznov et al., 1996, Protein Engineering 9:203-211). It may  
25 therefore be desirable to dissociate such tetramers and dimers using any methods known in the art. In one embodiment, streptavidin multimers are first denatured in a suitable denaturant, such as but is not limited to urea. The denatured proteins are then diluted to an appropriate  
concentration and allowed to refold into monomers.

30 Certain C-inteins, such as the engineered Mtu 35 aa C-intein, may misfold and form aggregate. This can normally be remedied by solubilizing and purifying the C-intein fragment in a suitable denaturant, such as but is not limited to urea. The denatured C-intein fragment can then be mixed with the N-  
35 intein fragment for reconstitution and trans-splicing.

### 5.3.3. RECONSTITUTION AND TRANS-SPLICING

In vitro trans-splicing can be carried out by adding the purified C-intein antigen recognition portion fragment to the  
5 purified N-intein anti-CR1 fragment in an appropriate reaction buffer. The reaction mixture is incubated at an appropriate temperature for an appropriate amount of time. The reaction temperature and incubation time depend in part on the specific trans-splicing system used and can be  
10 determined by one skilled in the art by standard methods, including but is not limited to monitoring the progress of the reaction by analyzing the reaction mixture by size exclusion HPLC or SDS-PAGE.

The concentrations of the intein fragments, i.e., the N-intein anti-CR1 and C-intein antigen recognition portion, can  
15 be adjusted for higher splicing efficiency and optimum reaction yield. Any methods known in the art can be used to determine the concentrations of proteins, such as but is not limited to the bichinchoninic acid method using BSA as  
20 standard (Smith et al., 1985, Anal. Biochem. 150:76-85). Normally, higher reactant concentrations is advantageous for increased yield. For certain split intein systems, however, higher reactant concentrations may lead to the formation of aggregates and the precipitation of one or both intein  
25 fragments. Under such circumstances, the concentration of one or both intein fragments can be optimized in small scale experiments before the production of the bispecific molecule. The concentrations of the intein fragments can also be adjusted such that the concentration of one intein fragment  
30 is higher than the other. This may be particularly useful when one of the intein fragment is more difficult and/or more expensive to produce. A higher concentration of one intein fragment permits more efficient use of the other intein fragment. In some embodiments of the invention, it may be desirable to conjugate two different antigen recognition  
35 portion to the two heavy or light chains of an anti-CR1 mAb. In such instances, the concentrations of the N-intein anti-

CR1 fragment and the two C-intein antigen recognition portion fragments can be adjusted according to the relative efficiency of the two trans-splicing reactions such that the yield for the desired bispecific molecule is optimized.

5 In cases where certain C-inteins, such as the engineered Mtu 35 aa C-intein, may misfold and form an aggregate, reconstitution can be carried out in a suitable denaturant, such as but is not limited to urea. The denaturant is then removed by methods known in the art, such as but is not  
10 limited to dialysis against a suitable buffer, to allow renaturation and trans-splicing.

Bispecific molecules can be purified by methods known to one skilled in the art using molecular size or specific binding affinity or a combination thereof. In one  
15 embodiment, the bispecific molecules can be purified by ion exchange chromatography using columns suitable for isolation of the bispecific molecules of the invention including DEAE, Hydroxylapatite, Calcium Phosphate (see generally Current Protocols in Immunology, 1994, John Wiley & Sons, Inc., New York, NY).

20 In another embodiment, bispecific molecules are purified by three-step successive affinity chromatography (Corvalan and Smith, 1987, Cancer Immunol. Immunother., 24:127-132): the first column is made of protein A bound to a solid matrix, wherein the Fc portion of the antibody binds protein  
25 A, and wherein the antibodies bind the column; followed by a second column that utilizes C3b-like receptor bound to a solid matrix which assays for C3b-like receptor binding via the anti-CR1 mAb portion of the bispecific molecule; and  
30 followed by a third column that utilizes specific binding of an antigenic molecule of interest which binds the antigen recognition portion of the bispecific molecule.

The bispecific molecules can also be purified by a combination of size exclusion HPLC and affinity chromatography. In one embodiment, the appropriate fraction  
35 eluted from size exclusion HPLC is further purified using a



column containing an antigenic molecule specific to the antigen recognition portion of the bispecific molecule.

The bispecific molecules may also be isolated by isoelectric focusing of antibodies.

5       The bispecific molecules can be characterized by various methods known in the art. In one embodiment, the bispecific molecules can be characterized by SDS-PAGE and Western blot. The molecular weight of the bispecific molecule is determined by SDS-PAGE. The bispecificity of the molecules in the  
10 appropriate band is then determined by Western blots using both CR1 and the antigenic molecule of interest. Alternatively, the bispecificity of the molecules can be determined by solid-phase immunoassays, such as enzyme-linked immunosorbent assays (ELISA). The structure of the  
15 bispecific molecule may further be verified by selective sequencing of the linker region of the proteolyzed bispecific molecule.

#### 5.3.4. PRODUCTION OF BISPECIFIC MOLECULES CONTAINING A STREPTAVIDIN-BIOTIN LINKER

20       Bispecific molecules comprising a streptavidin-biotin linker are produced using anti-CR1-streptavidin and biotinylated antigen recognition moiety. Any standard methods known in the art can be used to prepare the biotinylated antigen recognition moiety.

25       This configuration of the invention is particularly useful in producing bispecific molecules that comprises a mAb as the second antigen recognition portion that is conjugated to a C3b-like receptor recognition portion. Direct conjugation of an antigen recognition mAb using trans-  
30 splicing results a bispecific molecule wherein the amino terminus of the antigen recognition mAb is fused to the carboxy terminus of the anti-CR1 portion. The antigen binding affinity of this bispecific molecule may be compromised. On the other hand, it is known that  
35 biotinylation leads to negligible modification of the protein with retention of immunoreactivity (Foulon et al., 1999, Bioconjugate Chem. 10:867-876; Khawli et al., 1993, Antibody,

Immunoconjugates, Radiopharm. 6:13-27). Thus, using the streptavidin-biotin configuration of the invention offers a means to produce a bispecific molecule that comprises a mAb as the second antigen recognition portion. A mAb can be  
5 conjugated with biotin using various activated biotin agents, including but is not limited to NHS-LC-biotin. The biotin is preferably conjugated with a residue away from the antigen recognition domains of the mAb such that the antigen binding capability of the mAb and the bispecific molecule produced  
10 from the mAb is not impaired. For example, the biotin may be conjugated with the  $\epsilon$ -amino group of a lysine residue. More preferably, the biotin is conjugated with a residue near the carboxy terminus of the mAb. Biotinylated mAbs and bispecific molecules produced therefrom can be screened for  
15 functional antigen binding capabilities using any method that assays specific binding of an antigenic molecule which binds the antigen recognition portion of the mAb or the bispecific molecule. This configuration of the invention can also be used in producing bispecific molecules from pre-existing  
20 antibodies.

This configuration of the invention is also particularly useful in producing a bispecific molecule that comprises a non-proteinaceous antigen recognition moiety that is conjugated to a C3b-like receptor recognition portion, such  
25 as but is not limited to a nucleic acid. In one embodiment, a desired nucleic acid is amplified using a PCR primer containing a suitable restriction digestion site which, when cleaved by a restriction endonuclease, leaves an overhanging terminus. A biotinylated nucleotide, such as but is not  
30 limited to a biotinyl-dUTP, is then incorporated at the terminus using a DNA polymerase, such as but is not limited to DNA polymerase Klenow fragment (see, for example, U.S. Patent No. 6,060, 596). Methods for producing other biotinylated antigen recognition moieties will be recognized  
35 by one skilled in the art when a antigen recognition moiety is provided.

The biotinylated antigen recognition moiety can then be conjugated with the anti-CR1 portion of the bispecific molecule via a streptavidin-biotin linkage.

5           **5.3.5. IN VIVO PRODUCTION OF BISPECIFIC MOLECULES**

Bispecific molecules can also be produced in vivo. In one embodiment of the invention, bispecific molecules are produced in a suitable host cell. Nucleotide sequences encoding the N-intein anti-CR1 heavy chain fragment and the  
10 immunoglobulin light chain and the C-intein antigen recognition portion fragment are inserted into separate expression vectors, and are co-transfected into the host cell. Non-limiting examples of hosts include E. coli, yeast, insect cell, and mammalian host systems, such as a Chinese hamster ovary cell line. A mammalian cell line is preferable  
15 for the expression of anti-CR1 mAb. Employing separate expression vectors provides for the ability to adjust the proportions of each of the three polypeptide fragments in unequal ratios of the three polypeptide chains, thus providing optimum yields. In another embodiment, nucleotide  
20 sequences encoding the N-intein anti-CR1 heavy chain fragment and the immunoglobulin light chain and the C-intein antigen recognition portion fragment are inserted in one expression vector. The transfected cells can be induced to express the proteins by standard methods known in the art. Bispecific  
25 molecules can be purified by standard methods known in the art.

**5.4 PRODUCTION OF POLYCLONAL LIBRARIES OF BISPECIFIC MOLECULES USING PROTEIN TRANS-SPLICING**

30 Protein trans-splicing can also be used for producing libraries of bispecific molecules comprising a plurality of bispecific molecules with different antigen recognition specificities. Particularly of interest are polyclonal libraries wherein the plurality of antigen recognition  
35 portions has specificities for multiple epitopes of a targeted antigenic molecule and/or multiple variants of a

targeted antigenic molecule. Such polyclonal libraries of bispecific molecules can be used for more efficient clearance of pathogens that have multiple epitopes and/or pathogens that have multiple variants or mutants, which normally cannot  
5 be effectively targeted and cleared by a monoclonal antibody having a single specificity. By targeting multiple epitopes and/or multiple variants of a pathogen, the polyclonal library of bispecific molecules is advantageous in the clearance of pathogens that have a higher mutation rate  
10 because simultaneous mutations at more than one epitopes tend to be much less frequent.

In a preferred embodiment, nucleic acid encoding the C-intein of a split intein is recombinantly fused by any standard methods known in the art to the nucleic acid  
15 encoding a polypeptide antibody in a member of a phage display library such that the fused nucleic acid encodes a C-intein-polypeptide in which the N-terminus of the C-intein is fused to the C-terminus of the polypeptide antibody, thereby obtaining a phage display library displaying a repertoire of  
20 C-intein-polypeptides. Preferably, the number of specificities of such phage display library is near the number of different specificities that are expressed at any one time by lymphocytes of the immune system of a mammal, e.g.,  $10^7$  (or  $10^6$  to  $10^8$ ) different specificities by the murine immune system (see, e.g., Milstein, 1990, Proc. R.  
25 Soc. London B239:1-16). More preferably the number of specificities of the phage display library is higher than the number of different specificities that are expressed at any one time by lymphocytes of the immune system of a mammal. Most preferably the phage display library comprises the  
30 complete set of specificities that can be expressed by lymphocytes. Polyclonal C-intein antibody fusion proteins can then be obtained by affinity screening of the phage display library with an antigen of interest. Kits for generating and screening phage display libraries are  
35 commercially available (e.g., Pharmacia Recombinant Phage Antibody System, Catalog No. 27-9400-01; and the Stratagene

antigen SurfZAP™ Phage Display Kit, Catalog No. 240612). Additionally, examples of methods and reagents particularly amenable for use in generating and screening antibody display library can be found in, for example, U.S. Patent Nos.

5 5,223,409 and 5,514,548; PCT Publication No. WO 92/18619; PCT Publication No. WO 91/17271; PCT Publication No. WO 92/20791; PCT Publication No. WO 92/15679; PCT Publication No. WO 93/01288; PCT Publication No. WO 92/01047; PCT Publication No. WO 92/09690; PCT Publication No. WO 90/02809; Fuchs et  
10 al., 1991, Bio/Technology 9:1370-1372; Hay et al., 1992, Hum. Antibod. Hybridomas 3:81-85; Huse et al., 1989, Science 246:1275-1281; Griffiths et al., 1993, EMBO J. 12:725-734.

In other embodiments, polyclonal antibodies can be obtained by affinity screening of an antibody phage display library having a sufficiently large and diverse repertoire of  
15 specificities with an antigen of interest before recombinant fusion with a C-intein. The nucleic acid encoding each member of the selected antibodies is then fused to a C-intein of a suitable trans-splicing system and expressed in a  
20 suitable host. The C-intein antigen recognition portion fragments are allowed to reconstitute with the corresponding N-intein anti-CR1 fragments and undergo trans-splicing reactions.

In a preferred embodiment, the polyclonal library of bispecific molecules is produced using the whole collection  
25 of selected displayed antibodies without clonal isolation of individual members. The method for producing a polyclonal library of antibodies from a phage display library without clonal isolation is described in U.S. Patent No. 6,057,098, which is incorporated by reference herein in its entirety.  
30 Polyclonal antibodies are obtained by affinity screening of a phage display library having a sufficiently large repertoire of specificities with an antigenic molecule having multiple epitopes, preferably after enrichment of displayed library members that display multiple antibodies. The nucleic acids  
35 encoding the selected display antibodies are excised and amplified using suitable PCR primers. The nucleic acids can

be purified by gel electrophoresis such that the full length nucleic acids are isolated. Each of the nucleic acids is then fused to a C-intein of an appropriate trans-splicing system such that a population of expression vectors having  
5 different inserts is obtained. The population of expression vectors is then expressed in a suitable host or hosts. The population of C-intein antigen recognition fragments is then mixed with the N-intein anti-CR1 fragments to produce a library of bispecific molecules having a plurality of  
10 specificities.

In another preferred embodiment, the polyclonal library of bispecific molecules is produced from a population of displayed antibodies obtained by affinity screening with a set of antigens, such as but are not limited to a set of  
15 variants of a pathogen and/or a mixture of various pathogens. Such polyclonal library of bispecific molecules can be used to target and clear a set of antigens.

In still another preferred embodiment, the polyclonal library of bispecific molecules is produced using trans-splicing and a streptavidin-biotin linker. The plurality of  
20 antibodies is selected and produced by standard phage display procedure and is biotinylated. The plurality of biotinylated antibodies is then conjugated with anti-CR1 streptavidin molecules prepared by trans-splicing.

In still another preferred embodiment, a plurality of N-intein anti-CR1 mAb fragments comprising a plurality of anti-CR1 mAbs that target different sites on CR1 molecules of the red blood cells are mixed with the plurality of C-intein antigen recognition fragments with a plurality of  
25 specificities to produce a polyclonal library of bispecific molecules having polyclonal first and second antigen  
30 recognition portions.

Although polyclonal libraries of bispecific molecules produced from phage display libraries are described, it will be recognized by one skilled in the art that the plurality of  
35 second antigen recognition portions used in the generation of a library can be obtained from any population of suitable

antigen recognition moieties. Libraries of bispecific molecules produced from such population of antigen recognition moieties are intended to be within the scope of the invention.

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#### 5.5. USES OF BISPECIFIC MOLECULES

The bispecific molecules of the present invention are useful in treating or preventing a disease or disorder associated with the presence of a pathogenic antigenic molecule. The pathogenic antigenic molecule can be any substance that is present in the circulation that is potentially injurious to or undesirable in the subject to be treated, including but are not limited to proteins or drugs or toxins, autoantibodies or autoantigens, or a molecule of any infectious agent or its products. A pathogenic antigenic molecule is any molecule containing an antigenic determinant (or otherwise capable of being bound by a binding domain) that is or is part of a substance (e.g., a pathogen) that is the cause of a disease or disorder or any other undesirable condition.

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The preferred subject for administration of a bispecific antibody of the invention, for therapeutic or prophylactic purposes, is a mammal including but is not limited to non-human animals (e.g., horses, cows, pigs, dogs, cats, sheep, goats, mice, rats, etc.), and in a preferred embodiment, is a human or non-human primate.

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Circulating pathogenic antigenic molecules cleared by the fixed tissue phagocytes include any antigenic moiety that is harmful to the subject. Examples of harmful pathogenic antigenic molecules include any pathogenic antigenic molecule associated with a parasite, fungus, protozoa, bacteria, or virus. Furthermore, circulating pathogenic antigenic molecules may also include toxins, immune complexes, autoantibodies, drugs, an overdose of a substance, such as a barbiturate, or anything that is present in the circulation and is undesirable or detrimental to the health of the host mammal. Failure of the immune system to effectively remove

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the pathogenic antigenic molecules from the mammalian circulation can lead to traumatic and hypovolemic shock (Altura and Hershey, 1968, Am. J. Physiol. 215:1414-9).

Moreover, non-pathogenic antigens, for example  
5 transplantation antigens, are mistakenly perceived to be harmful to the host and are attacked by the host immune system as if they were pathogenic antigenic molecules. The present invention further provides an embodiment for treating transplantation rejection comprising administering to a  
10 subject an effective amount of a bispecific antibody that will bind and remove immune cells or factors involved in transplantation rejection, e.g., transplantation antigen specific antibodies.

#### 15 5.5.1 AUTOIMMUNE ANTIGENS

In one embodiment, the pathogenic antigenic molecule to be cleared from the circulation includes autoimmune antigens. These antigens include but are not limited to autoantibodies or naturally occurring molecules associated with autoimmune  
20 diseases.

As one example, certain humans with hemophilia have been shown to be deficient in factor VIII. Recombinant factor VIII replacement treats this hemophilia. However, eventually some patients develop antibodies against factor VIII, thus  
25 interfering with the therapy. The bispecific antibodies of the present invention prepared with an anti-anti-factor VIII antibody provides a therapeutic solution for this problem. In particular, a bispecific antibody with specificity of the first antigen recognition portion to a C3b-like receptor and specificity of the second antigen recognition portion to an  
30 anti-factor VIII autoantibody would be therapeutically useful in clearing the autoantibodies from the circulation, thus, ameliorating the disease.

Further examples of autoantibodies which can be cleared by the bispecific antibodies of the present invention  
35 include, but are not limited to, autoantibodies to the following antigens: the muscle acetylcholine receptor (the



antibodies are associated with the disease myasthenia gravis); cardiolipin (associated with the disease lupus); platelet associated proteins (associated with the disease idiopathic thrombocytopenic purpura); the multiple antigens  
5 associated with Sjogren's Syndrome; the antigens implicated in the case of tissue transplantation autoimmune reactions; the antigens found on heart muscle (associated with the disease autoimmune myocarditis); the antigens associated with immune complex mediated kidney disease; the dsDNA and ssDNA  
10 antigens (associated with lupus nephritis); desmogleins and desmoplakins (associated with pemphigus and pemphigoid); or any other antigen which is characterized and is associated with disease pathogenesis.

When the above bispecific antibodies are injected into  
15 the circulation of a human or non-human primate, the bispecific antibodies will bind to red blood cells via the human or primate C3b receptor domain recognition site, at a high percentage and in agreement with the number of C3b-like receptor sites on red blood cells. The bispecific antibodies  
20 will simultaneously associate with the autoantibody indirectly, through the antigen, which is bound to the monoclonal antibody. The red blood cells which have the bispecific antibody/autoantibody complex on their surface then facilitate the neutralization and clearance from the circulation of the bound pathogenic autoantibody.

25 In the present invention, the bispecific antibodies facilitate pathogenic antigen or autoantibody binding to hematopoietic cells expressing a C3b-like receptor on their surface and subsequently clear the pathogenic antigen or autoantibody from the circulation, without also clearing the  
30 hematopoietic cells.

#### 5.5.2 INFECTIOUS DISEASES

In specific embodiments, infectious diseases are treated or prevented by administration of a bispecific molecule that  
35 binds both an antigen of an infectious disease agent and a C3b-like receptor. Thus, in such an embodiment, the

pathogenic antigenic molecule is an antigen of an infectious disease agent.

Such antigen can be but is not limited to: influenza virus hemagglutinin (Genbank accession no. J02132; Air, 1981, Proc. Natl. Acad. Sci. USA 78:7639-7643; Newton et al., 1983, Virology 128:495-501), human respiratory syncytial virus G glycoprotein (Genbank accession no. Z33429; Garcia et al., 1994, J. Virol.; Collins et al., 1984, Proc. Natl. Acad. Sci. USA 81:7683), core protein, matrix protein or other protein of Dengue virus (Genbank accession no. M19197; Hahn et al., 1988, Virology 162:167-180), measles virus hemagglutinin (Genbank accession no. M81899; Rota et al., 1992, Virology 188:135-142), herpes simplex virus type 2 glycoprotein gB (Genbank accession no. M14923; Bzik et al., 1986, Virology 155:322-333), poliovirus I VP1 (Emini et al., 1983, Nature 304:699), envelope glycoproteins of HIV I (Putney et al., 1986, Science 234:1392-1395), hepatitis B surface antigen (Itoh et al., 1986, Nature 308:19; Neurath et al., 1986, Vaccine 4:34), diphtheria toxin (Audibert et al., 1981, Nature 289:543), streptococcus 24M epitope (Beachey, 1985, Adv. Exp. Med. Biol. 185:193), gonococcal pilin (Rothbard and Schoolnik, 1985, Adv. Exp. Med. Biol. 185:247), pseudorabies virus g50 (gpD), pseudorabies virus II (gpB), pseudorabies virus gIII (gpC), pseudorabies virus glycoprotein H, pseudorabies virus glycoprotein E, transmissible gastroenteritis glycoprotein 195, transmissible gastroenteritis matrix protein, swine rotavirus glycoprotein 38, swine parvovirus capsid protein, Serpulina hydodysenteriae protective antigen, bovine viral diarrhea glycoprotein 55, Newcastle disease virus hemagglutinin-neuraminidase, swine flu hemagglutinin, swine flu neuraminidase, foot and mouth disease virus, hog colera virus, swine influenza virus, African swine fever virus, Mycoplasma hyopneumoniae, infectious bovine rhinotracheitis virus (e.g., infectious bovine rhinotracheitis virus glycoprotein E or glycoprotein G), or infectious laryngotracheitis virus (e.g., infectious laryngotracheitis

virus glycoprotein G or glycoprotein I), a glycoprotein of La Crosse virus (Gonzales-Scarano et al., 1982, Virology 120:42), neonatal calf diarrhea virus (Matsuno and Inouye, 1983, Infection and Immunity 39:155), Venezuelan equine encephalomyelitis virus (Mathews and Roehrig, 1982, J. Immunol. 129:2763), punta toro virus (Dalrymple et al., 1981, Replication of Negative Strand Viruses, Bishop and Compans (eds.), Elsevier, NY, p. 167), murine leukemia virus (Steeves et al., 1974, J. Virol. 14:187), mouse mammary tumor virus (Massey and Schochetman, 1981, Virology 115:20), hepatitis B virus core protein and/or hepatitis B virus surface antigen or a fragment or derivative thereof (see, e.g., U.K. Patent Publication No. GB 2034323A published June 4, 1980; Ganem and Varmus, 1987, Ann. Rev. Biochem. 56:651-693; Tiollais et al., 1985, Nature 317:489-495), of equine influenza virus or equine herpesvirus (e.g., equine influenza virus type A/Alaska 91 neuraminidase, equine influenza virus type A/Miami 63 neuraminidase, equine influenza virus type A/Kentucky 81 neuraminidase equine herpesvirus type 1 glycoprotein B, and equine herpesvirus type 1 glycoprotein D, antigen of bovine respiratory syncytial virus or bovine parainfluenza virus (e.g., bovine respiratory syncytial virus attachment protein (BRSV G), bovine respiratory syncytial virus fusion protein (BRSV F), bovine respiratory syncytial virus nucleocapsid protein (BRSV N), bovine parainfluenza virus type 3 fusion protein, and the bovine parainfluenza virus type 3 hemagglutinin neuraminidase), bovine viral diarrhea virus glycoprotein 48 or glycoprotein 53.

Additional diseases or disorders that can be treated or prevented by the use of a bispecific molecule of the present invention include, but are not limited to, those caused by hepatitis type A, hepatitis type B, hepatitis type C, influenza, varicella, adenovirus, herpes simplex type I (HSV-I), herpes simplex type II (HSV-II), rinderpest, rhinovirus, echovirus, rotavirus, respiratory syncytial virus, papilloma virus, papova virus, cytomegalovirus, echinovirus, arbovirus, hantavirus, coxsackie virus, mumps

virus, measles virus, rubella virus, polio virus, human immunodeficiency virus type I (HIV-I), and human immunodeficiency virus type II (HIV-II), any picornaviridae, enteroviruses, caliciviridae, any of the Norwalk group of  
5 viruses, togaviruses, such as Dengue virus, alphaviruses, flaviviruses, coronaviruses, rabies virus, Marburg viruses, ebola viruses, parainfluenza virus, orthomyxoviruses, bunyaviruses, arenaviruses, reoviruses, rotaviruses, orbiviruses, human T cell leukemia virus type I, human T cell  
10 leukemia virus type II, simian immunodeficiency virus, lentiviruses, polyomaviruses, parvoviruses, Epstein-Barr virus, human herpesvirus-6, cercopithecine herpes virus 1 (B virus), and poxviruses.

Bacterial diseases or disorders that can be treated or  
15 prevented by the use of bispecific molecules of the present invention include, but are not limited to, Mycobacteria rickettsia, Mycoplasma, Neisseria spp. (e.g., Neisseria meningitidis and Neisseria gonorrhoeae), Legionella, Vibrio cholerae, Streptococci, such as Streptococcus pneumoniae, Corynebacteria diphtheriae, Clostridium tetani, Bordetella  
20 pertussis, Haemophilus spp. (e.g., influenzae), Chlamydia spp., enterotoxigenic Escherichia coli, and Bacillus anthracis (anthrax), etc.

Protozoal diseases or disorders that can be treated or  
25 prevented by the use of bispecific molecules of the present invention include, but are not limited to, plasmodia, eimeria, Leishmania, and trypanosoma.

### 5.5.3 ADDITIONAL PATHOGENIC ANTIGENIC MOLECULES

In one embodiment, the pathogenic antigenic molecule to  
30 be cleared from the circulation by the methods and compositions of the present invention encompass any serum drug, including but is not limited to barbiturates, tricyclic antidepressants, and Digitalis.

In another embodiment, the pathogenic antigenic molecule  
35 to be cleared includes any serum antigen that is present as an overdose and can result in temporary or permanent

impairment or harm to the subject. This embodiment particularly relates to drug overdoses.

In another embodiment, the pathogenic antigenic molecule to be cleared from the circulation include naturally occurring substances. Examples of naturally occurring pathogenic antigenic molecules that could be removed by the methods and compositions of the present invention include but are not limited to low density lipoproteins, interleukins or other immune modulating chemicals and hormones.

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#### 5.5.4. COCKTAILS OF BISPECIFIC MOLECULES

Various purified bispecific molecules can be combined into a "cocktail" of bispecific molecules. Such cocktail of bispecific molecules can include bispecific molecules having an anti-CR1 mAb as the first antigen recognition portion and any one of several desired antigen recognition moieties as the second antigen recognition portion. For example, the bispecific molecule cocktail comprises a plurality of different bispecific molecules, wherein each different bispecific molecule in the plurality contains a different second antigen recognition portion that targets a different pathogens; the second antigen recognition portions can be proteinaceous and/or non-proteinaceous moieties. Such bispecific molecule cocktails are useful as personalized medicine tailored according to the need of individual patients.

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#### 5.5.5. DOSE OF BISPECIFIC ANTIBODIES

The dose can be determined by a physician upon conducting routine experiments. Prior to administration to humans, the efficacy is preferably shown in animal models. Any animal model for a circulatory disease known in the art can be used.

More particularly, the dose of the bispecific antibody can be determined based on the hematopoietic cell concentration and the number of C3b-like receptor epitope sites bound by the anti-C3b-like receptor monoclonal

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antibodies per hematopoietic cell. If the bispecific antibody is added in excess, a fraction of the bispecific antibody will not bind to hematopoietic cells, and will inhibit the binding of pathogenic antigens to the hematopoietic cell. The reason is that when the free bispecific antibody is in solution, it will compete for available pathogenic antigen with bispecific antibody bound to hematopoietic cells. Thus, the bispecific antibody-mediated binding of the pathogenic antigens to hematopoietic cells follows a bell-shaped curve when binding is examined as a function of the concentration of the input bispecific antibody concentration.

Viremia may result in up to  $10^8$ - $10^9$  viral particles/ml of blood (HIV is  $10^6$ /ml; (Ho, 1997, J. Clin. Invest. 99:2565-2567)); the dose of therapeutic bispecific antibodies should preferably be, at a minimum, approximately 10 times the antigen number in the blood.

In general, for antibodies, the preferred dosage is 0.1 mg/kg to 100 mg/kg of body weight (generally 10 mg/kg to 20 mg/kg). If the antibody is to act in the brain, a dosage of 50 mg/kg to 100 mg/kg is usually appropriate. Generally, partially human antibodies and fully human antibodies have a longer half-life within the human body than other antibodies. Accordingly, lower dosages and less frequent administration are often possible. Modifications such as lipidation can be used to stabilize antibodies and to enhance uptake and tissue penetration (e.g., into the brain). A method for lipidation of antibodies is described by Cruikshank et al. ((1997) J. Acquired Immune Deficiency Syndromes and Human Retrovirology 14:193).

As defined herein, a therapeutically effective amount of bispecific antibody (i.e., an effective dosage) ranges from about 0.001 to 30 mg/kg body weight, preferably about 0.01 to 25 mg/kg body weight, more preferably about 0.1 to 20 mg/kg body weight, and even more preferably about 1 to 10 mg/kg, 2 to 9 mg/kg, 3 to 8 mg/kg, 4 to 7 mg/kg, or 5 to 6 mg/kg body weight.

The skilled artisan will appreciate that certain factors may influence the dosage required to effectively treat a subject, including but is not limited to the severity of the disease or disorder, previous treatments, the general health and/or age of the subject, and other diseases present. Moreover, treatment of a subject with a therapeutically effective amount of a bispecific antibody can include a single treatment or, preferably, can include a series of treatments. In a preferred example, a subject is treated with a bispecific antibody in the range of between about 0.1 to 20 mg/kg body weight, one time per week for between about 1 to 10 weeks, preferably between 2 to 8 weeks, more preferably between about 3 to 7 weeks, and even more preferably for about 4, 5, or 6 weeks. It will also be appreciated that the effective dosage of a bispecific antibody, used for treatment may increase or decrease over the course of a particular treatment. Changes in dosage may result and become apparent from the results of diagnostic assays as described herein.

It is understood that appropriate doses of bispecific antibody agents depends upon a number of factors within the ken of the ordinarily skilled physician, veterinarian, or researcher. The dose(s) of the bispecific antibody will vary, for example, depending upon the identity, size, and condition of the subject or sample being treated, further depending upon the route by which the composition is to be administered, if applicable, and the effect which the practitioner desires the bispecific antibody to have upon a pathogenic antigenic molecule or autoantibody.

It is also understood that appropriate doses of bispecific antibodies depend upon the potency of the bispecific antibody with respect to the antigen to be cleared. Such appropriate doses may be determined using the assays described herein. When one or more of these bispecific antibodies is to be administered to an animal (e.g., a human) in order to clear an antigen, a physician, veterinarian, or researcher may, for example, prescribe a

relatively low dose at first, subsequently increasing the dose until an appropriate response is obtained. In addition, it is understood that the specific dose level for any particular animal subject will depend upon a variety of factors including the activity of the bispecific antibody employed, the age, body weight, general health, gender, and diet of the subject, the time of administration, the route of administration, the rate of excretion, any drug combination, and the concentration of antigen to be cleared.

#### 5.5.6. PHARMACEUTICAL FORMULATION AND ADMINISTRATION

The bispecific antibodies of the invention can be incorporated into pharmaceutical compositions suitable for administration. Such compositions typically comprise bispecific antibody and a pharmaceutically acceptable carrier. As used herein the language "pharmaceutically acceptable carrier" is intended to include any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like, compatible with pharmaceutical administration. The use of such media and agents for pharmaceutically active substances is well known in the art. Except insofar as any conventional media or agent is incompatible with the bispecific antibody, use thereof in the compositions is contemplated. Supplementary bispecific antibodies can also be incorporated into the compositions.

A pharmaceutical composition of the invention is formulated to be compatible with its intended route of administration. The preferred route of administration is intravenous. Other examples of routes of administration include parenteral, intradermal, subcutaneous, transdermal (topical), and transmucosal. Solutions or suspensions used for parenteral, intradermal, or subcutaneous application can include the following components: a sterile diluent such as water for injection, saline solution, fixed oils, polyethylene glycols, glycerine, propylene glycol or other synthetic solvents; antibacterial agents such as benzyl



alcohol or methyl parabens; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid; buffers such as acetates, citrates or phosphates and agents for the adjustment of  
5 tonicity such as sodium chloride or dextrose. pH can be adjusted with acids or bases, such as hydrochloric acid or sodium hydroxide. The parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic.

10 Pharmaceutical compositions suitable for injectable use include sterile aqueous solutions (where water soluble) or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersions. For intravenous administration, suitable carriers include  
15 physiological saline, bacteriostatic water, Cremophor EL™ (BASF; Parsippany, NJ) or phosphate buffered saline (PBS). In all cases, the composition must be sterile and should be fluid to the extent that the viscosity is low and the bispecific antibody is injectable. It must be stable under  
20 the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms such as bacteria and fungi.

The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol,  
25 and the like), and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Prevention of the action of microorganisms can  
30 be achieved by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, ascorbic acid, thimerosal, and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, sodium chloride in  
35 the composition. Prolonged absorption of the injectable compositions can be brought about by including in the

composition an agent which delays absorption, for example, aluminum monostearate and gelatin.

Sterile injectable solutions can be prepared by incorporating the bispecific antibody (e.g., one or more  
5 bispecific antibodies) in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the bispecific antibody into a sterile vehicle  
10 which contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying which yields a powder of the active  
15 ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

In one embodiment, the bispecific antibodies are prepared with carriers that will protect the compound against rapid elimination from the body, such as a controlled release  
20 formulation, including implants and microencapsulated delivery systems. Biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters, and polylactic acid. Methods for preparation of such formulations will be apparent to those skilled in the art. The materials can also  
25 be obtained commercially from Alza Corporation and Nova Pharmaceuticals, Inc. Liposomal suspensions (including liposomes targeted to infected cells with monoclonal antibodies to viral antigens) can also be used as pharmaceutically acceptable carriers. These can be prepared  
30 according to methods known to those skilled in the art, for example, as described in U.S. Patent No. 4,522,811 which is incorporated herein by reference in its entirety.

It is advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity  
35 of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the

subject to be treated; each unit containing a predetermined quantity of bispecific antibody calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the dosage unit forms of the invention are dictated by and directly  
5 dependent on the unique characteristics of the bispecific antibody and the particular therapeutic effect to be achieved, and the limitations inherent in the art of compounding such a bispecific antibody for the treatment of  
10 individuals.

The pharmaceutical compositions can be included in a kit, in a container, pack, or dispenser together with instructions for administration.

15 **5.5.7. EX VIVO PREPARATION OF THE BISPECIFIC MOLECULE**

In an alternative embodiment, the bispecific molecule, such as a bispecific antibody, is prebound to hematopoietic cells of the subject ex vivo, prior to administration. For example, hematopoietic cells are collected from the  
20 individual to be treated (or alternatively hematopoietic cells from a non-autologous donor of the compatible blood type are collected) and incubated with an appropriate dose of the therapeutic bispecific antibody for a sufficient time so as to allow the antibody to bind the C3b-like receptor on the  
25 surface of the hematopoietic cells. The hematopoietic cell/bispecific antibody mixture is then administered to the subject to be treated in an appropriate dose (see, for example, Taylor et al., U.S. Patent No. 5,487,890).

The hematopoietic cells are preferably blood cells, most preferably red blood cells.

30 Accordingly, in a specific embodiment, the invention provides a method of treating a mammal having an undesirable condition associated with the presence of a pathogenic antigenic molecule, comprising the step of administering a hematopoietic cell/bispecific molecule complex to the subject  
35 in a therapeutically effective amount, said complex consisting essentially of a hematopoietic cell expressing a

C3b-like receptor bound to one or more bispecific molecules. The method alternatively comprises a method of treating a mammal having an undesirable condition associated with the presence of a pathogenic antigenic molecule comprising the steps of (a) contacting a bispecific molecule with hematopoietic cells expressing a C3b-like receptor, to form a hematopoietic cell/bispecific molecule complex; and (b) administering the hematopoietic cell/bispecific molecule complex to the mammal in a therapeutically effective amount.

The invention also provides a method of making a hematopoietic cell/bispecific molecule complex comprising contacting a bispecific molecule with hematopoietic cells that express a C3b-like receptor under conditions conducive to binding, such that a complex forms, said complex consisting essentially of a hematopoietic cell bound to one or more bispecific molecules.

Taylor et al. (U.S. Patent No. 5,879,679, hereinafter "the '679 patent") have demonstrated in some instances that the system saturates because the concentration of autoantibodies (or other pathogenic antigen) in the plasma is so high that even at the optimum input of bispecific antibodies, not all of the autoantibodies can be bound to the hematopoietic cells under standard conditions. For example, for a very high titer of autoantibody sera, a fraction of the autoantibody is not bound to the hematopoietic cells due to its high concentration.

However, saturation can be solved by using combinations of bispecific antibodies which contain monoclonal antibodies that bind to different sites on a C3b-like receptor. For example, the monoclonal antibodies 7G9 and 1B4 bind to separate and non-competing sites on the primate C3b receptor. Therefore, a "cocktail" containing a mixture of two bispecific antibodies, each made with a different monoclonal antibody to the C3b-like receptor, may give rise to greater binding of antibodies to red blood cells. The bispecific antibodies of the present invention can also be used in

combination with certain fluids used for intravenous infusions.

In yet another embodiment, the bispecific molecule, such as a bispecific antibody, is prebound to red blood cells in vitro as described above, using a blend of at least two different bispecific antibodies. In this embodiment, the two different bispecific antibodies bind to the same antigen, but also bind to distinct and non-overlapping recognition sites on the C3b-like receptor. By using at least two non-overlapping bispecific antibodies for binding to the C3b-like receptor, the number of bispecific antibody-antigen complexes that can bind to a single red blood cell is increased. Thus, by allowing more than one bispecific antibody to bind to a single C3b-like receptor, antigen clearance is enhanced, particularly in cases where the antigen is in very high concentrations (see for example the '679 patent, column 6, lines 41-64).

#### 5.6. KITS

The invention also provides kits containing the intein antigen recognition portion fragments of the invention, or one or more nucleic acids encoding the intein antigen recognition portion fragments of the invention, or cells transformed with such nucleic acids, in one or more containers. The nucleic acids can be integrated into the chromosome, or exist as vectors (e.g., plasmids, particularly plasmid expression vectors). Kits containing the pharmaceutical compositions of the invention are also provided.

#### 5.7. PROTEIN TRANS-SPlicing FOR PRODUCING OTHER BISPECIFIC MOLECULES

Although protein trans-splicing is useful in producing bispecific molecules that bind a C3b-like receptor and an antigen, it will be recognized by one skilled in the art that other bispecific molecules can also be produced by protein trans-splicing. It is the intention that the production of such bispecific molecules is also within the scope of the

present invention. As a non-limiting example, protein trans-splicing can be used for the production of bispecific molecules that comprise an antigen recognition portion that binds the transferrin receptor, such as but is not limited to an anti-transferrin receptor mAb, and an antigen recognition portion that binds an appropriate receptor in the brain, such as but is not limited to a peptide therapeutic molecule that binds the epidermal growth factor receptor in the brain. The anti-transferrin receptor mAb can undergo receptor-mediated transcytosis through the brain capillary endothelial wall which forms the blood-brain barrier (BBB). Therefore, the bispecific molecules are useful in the delivery to the brain drugs that are otherwise not transportable through BBB (see, for example, Deguchi et al., 1999, Bioconjugate Chem. 10:32-37; Li et al., 1999, Protein Engineering 12:787-796).

**6. EXAMPLE: BISPECIFIC MOLECULE COMPRISING ANTI-CR1 mAb X  $\alpha$ -SUBUNIT OF Fc $\epsilon$ RI FOR REMOVING IgE**

The following example describes the production of a bispecific molecule comprising an anti-CR1 mAb and the  $\alpha$ -subunit of Fc $\epsilon$ RI. This example is a preferred embodiment of the invention.

IgE has been implicated in many allergic diseases. Fc $\epsilon$ RI is a human IgE receptor that plays an important role in the induction and maintenance of an allergic response (Saban et al., 1994, J. Allergy Clin. Immunol. 94:836-843; Turner et al., 1999, Nature 402:B24-B30; Chang, 2000, Nature Biotechnology 18:157-162). Of the three subunits that compose the Fc $\epsilon$ RI, i.e., the  $\alpha$ -,  $\beta$ - and  $\gamma$ -subunits, the  $\alpha$ -subunit binds the Fc portion of IgE. It has been found that the  $\alpha$ -subunit of the Fc $\epsilon$ RI is sufficient for high affinity IgE binding, whereas the  $\beta$ - and  $\gamma$ -subunits do not play a critical role in IgE binding (Hakimi et al., J. Biol. Chem. 265:22079-22081). A bispecific molecule comprising an anti-CR1 mAb and the  $\alpha$ -subunit of Fc $\epsilon$ RI is therefore useful in treating IgE-mediated diseases by removing IgE from the circulation.

Hybridoma cell line ATCC HB 8592 is obtained from the American Type Culture Collection (ATCC). Hybridomas are grown to log phase in Dulbecco's Modified Eagle's Medium (DMEM). Total RNA is isolated from 10<sup>7</sup> hybridoma cells. The  
5 hybridoma cells are first washed in PBS. The cells are then resuspended in 1ml buffer GTC (4M Guanidine-Isothiocyanate, 25mM Sodium Citrate, 0.5% Sarcosyl, 0.1M b-mercaptoethanol). 0.1 ml sodium acetate (3M, pH 5.2), 0.5 ml phenol, and 0.2 ml chloroform are then added to the cell suspension. The cell  
10 suspension is then centrifuged at 10,000 x g for 15 minutes. Supernatant is precipitated using 1 volume of isopropanol and is centrifuged at 10,000 x g for 15 minutes. The pellet is washed in 70% EtOH and allowed air dry before is resuspended in 100 ml DEPC-treated water.

15 cDNA is prepared by adding 10 ml of RNA to a buffer comprising 5 ml 10x RT buffer(0.5 M Tris-HCl(pH 8.2), 0.1 M MgCl<sub>2</sub>, and 1 M KCl), 5 ml DTT(100mM), 5 ml dNTP(5mM each), 1 ml oligonucleotides(10pmols/ml each), 5 ml RNasin(10u/ml), 5 ml RTase(100u/ml), and 14 ml H<sub>2</sub>O and incubating at 37°C for 1  
20 hour. The reaction mixture is then boiled for 3 minutes and quenched on ice.

PCR amplification is carried out using 5-10 ml cDNA in a buffer comprising 2.5 ml each forward and reverse primers(10 pmol/ml each) 5 ml 10x PCR buffer(0.1 M Tris-HCl(pH 8.3), 15  
25 mM MgCl<sub>2</sub>, and 0.5 M KCl), 2.5 ml dNTP (5mM each), 0.5 ml BSA(10mg/ml), and about 50 ml H<sub>2</sub>O. The reaction mixture is overlaid with parafin oil and heated to 94°C for 5 minutes in PCR block before 0.5 to 1 Tag DNA polymerase(5u/ml) is added. 30 temperature cycles: 94°C 1 minute, 60°C 1 minute, 72°C 2 minutes are used.

30 PCR products are purified by gel electrophoresis. Heavy and light chains.

The N-intein of the Ssp DnaE gene is amplified from plasmid pDnaE-C-209 with primers 5'-TTTGGTACCGAAATTTTAA-  
CCGTTGAG-3' (SEQ ID NO.: 5) and 5'-  
35 GGCTCTTCCTTTAAATTGTCCCAGCGTCAAG-3' (SEQ ID NO.: 6) . The N-terminal splice junction sequence containing the 5 intein N-

terminal residues and 5 native N-extein residues are ligated to the C-terminus of the amplified product.

The extended C-intein of the Ssp DnaE gene consisting the C-intein and a cysteine is prepared by peptide synthesis with N-(9-fluorenyl)methoxycarbonyl chemistry on an Applied Biosystems Model 431 peptide synthesizer using 4-methyl benzhydrylamine resin (Novabiochem), O-trityl-protected threonine, double coupling of all threonine and arginine residues, an acetic anhydride blocking step at each cycle, and N-methylpyrrolidone supplemented with dimethyl sulfoxide to 10%. The peptide is cleaved from the resin and deprotected with 6.25%(w/v) phenol in thioanisole:1,2-ethanedithiol:water:trifluoroacetic acid (2:1:2:20). The peptides are purified by HPLC (Rainin) using a preparative C8 column (Vydac).

The sequence of nucleic acid encoding the  $\alpha$ -subunit of human Fc $\epsilon$ RI is given in Kochan et al., 1988, Nucleic Acids Research 16:3584 (Accession No. X06948).

The nucleic acid encoding the Ssp N-intein is fused to the nucleic acid encoding the heavy chain of the anti-CR1 mAb such that a fusion protein that consists of the N-terminus of the Ssp N-intein fused to the C-terminus of the heavy chain of the anti-CR1 mAb is encoded. Vectors containing the nucleic acid encoding the fusion polypeptide fragment and the nucleic acid encoding the light chain of the anti-CR1 mAb are constructed by operably linking the nucleic acids to the simian virus 40 regulatory elements according to Mulligan et al., 1980, Science 209:1423-1427. The two vectors are co-transfected into CHO cells according to Subramani et al. (Subramani et al., 1981, J. Mol. Cell. Biol. 1:854-864) for the production of N-intein anti-CR1 mAb.

DNA construct containing the  $\alpha$ -subunit of human Fc $\epsilon$ RI is constructed according to Hakimi et al., 1990, J. Biol. Chem. 265:22079-22081. Nucleic acid encoding the Ssp C-intein is then fused to the DNA construct containing the  $\alpha$ -subunit of human Fc $\epsilon$ RI. The DNA construct containing the Ssp C-intein fused to the  $\alpha$ -subunit is transfected into CHO cells for



production according to Haak-Frendscho et al., 1993, J. Immunol. 151:351-8.

The N-intein anti-CR1 fragment and the C-intein FcεRI α-subunit fragment are mixed in reaction buffer (100 mM Tris-HCl, pH 7.0, containing 500 mM NaCl). The final concentrations of the N-intein and C-intein fragments are both 500 mM. The mixture is allowed to react at room temperature overnight.

The bispecific molecules are purified by three-step successive affinity chromatography: the first column is made of protein A bound to a solid matrix, where the Fc portion of the antibody binds protein A, and wherein the antibodies bind the column; followed by a second column that utilizes CR1 binding to a solid matrix which assays for CR1 binding via the anti-CR1 mAb portion of the bispecific molecule; and followed by a third column that utilizes specific binding of IgE bound by the FcεRI portion of the bispecific molecule.

The bispecific molecules can be characterized by SDS-PAGE and Western blot. The molecular weight of the bispecific molecule is determined by SDS-PAGE. The bispecificity of the molecules in the appropriate band is then determined by Western blots with both CR1 and the antigen of interest.

## 7. REFERENCES CITED

All references cited herein are incorporated herein by reference in their entirety and for all purposes to the same extent as if each individual publication or patent or patent application was specifically and individually indicated to be incorporated by reference in its entirety for all purposes.

Many modifications and variations of this invention can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. The specific embodiments described herein are offered by way of example only, and the invention is to be limited only by the terms of the appended claims along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. A method of producing a bispecific molecule having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds  
5 a pathogenic antigenic molecule, comprising contacting an N-intein first antigen recognition portion and a C-intein second antigen recognition portion under conditions such that protein trans-splicing occurs, wherein said N-intein first antigen recognition portion comprises said first antigen  
10 recognition portion conjugated to the amino terminus of an N-intein of a split intein, and wherein said C-intein second antigen recognition portion comprises said second antigen recognition portion conjugated to the carboxy terminus of a C-intein of said split intein, wherein the amino acid residue  
15 immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

2. A method of producing a bispecific molecule having a first antigen recognition portion that binds a C3b-like  
20 receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, comprising:

(a) obtaining an N-intein first antigen recognition portion by conjugating said first antigen recognition portion to the amino terminus of a molecule comprising an N-intein of  
25 a split intein;

(b) obtaining a C-intein second antigen recognition portion by conjugating said second antigen recognition portion to the carboxy terminus of a molecule comprising a C-intein of said split intein, wherein the amino acid residue  
30 immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine; and

(c) contacting said N-intein first antigen recognition portion and said C-intein second antigen  
35 recognition portion under conditions such that protein trans-splicing occurs, to produce said bispecific molecule.

3. The method of claim 1 or 2, wherein said split intein is a naturally occurring split intein.

4. The method of claim 3, wherein the sequence of the N-intein of said split intein is SEQ ID NO:1, and the sequence of the C-intein of said split intein is SEQ ID NO:2.

5. The method of claim 1 or 2, wherein said split intein is an engineered split intein generated by separating a naturally occurring non-split intein into an amino terminal fragment and a carboxy terminal fragment such that said amino terminal fragment and said carboxy terminal fragment can reconstitute and undergo trans-splicing.

6. The method of claim 5, wherein said engineered split intein is generated from the *Mycobacterium tuberculosis* RecA intein.

7. The method of claim 1 or 2, wherein said N-intein further comprises a sequence of 1 or more native proximal N-extein amino acid residue(s) attached to the amino terminus of said N-intein.

8. The method of claim 7, wherein said N-intein comprises a sequence of 3 to 5 native proximal N-extein amino acid residue(s) attached to the amino terminus of said N-intein.

9. The method of claim 1 or 2, wherein said C-intein further comprises an amino acid residue selected from the group consisting of cysteine, serine, and threonine at the carboxy terminus of the splice junction.

10. The method of claim 9, wherein said C-intein further comprises a sequence of 1 or more native proximal C-extein

amino acid residue(s) attached to the carboxy terminus of said C-intein.

11. The method of claim 10, wherein said C-intein comprises  
5 a sequence of 3 to 5 more native proximal C-extein amino acid residue(s) attached to the carboxy terminus of said C-intein.

12. The method of claim 1 or 2, wherein said N-intein  
comprises an unnatural amino acid residue such that upon  
10 conversion of said unnatural amino acid residue into normal amino acid residues by a suitable means said N-intein becomes functional for trans-splicing.

13. The method of claim 12, wherein said unnatural amino  
15 acid residue is O-(2-nitrobenzyl)serine, and said suitable means comprises irradiating using light having a wavelength in the range of 300-350 nm.

14. The method of claim 1 or 2, wherein said first antigen  
20 recognition portion comprises an antigen binding domain that binds a C3b-like receptor on a mammalian blood cell and an effector domain that facilitates transfer of said pathogenic antigen molecule from said mammalian blood cell to a phagocytic cell.

25 15. The method of claim 1 or 2, wherein said first antigen recognition portion is an monoclonal antibody.

16. The method of claim 15, wherein said N-intein first  
30 antigen recognition portion is generated by conjugating the carboxy terminus of the heavy chain of said monoclonal antibody to said amino terminus of said N-intein.

17. The method of claim 15, wherein said N-intein first  
35 antigen recognition portion fragment is generated by conjugating the carboxy terminus of the light chain of said monoclonal antibody to the amino terminus of said N-intein.

18. The method of claim 1 or 2, wherein said first antigen recognition portion is an ScFv that binds a C3b-like receptor fused to the N-terminus of an immunoglobulin Fc domain.
- 5 19. The method of claim 1 or 2, wherein said second antigen recognition portion comprises a polypeptide.
20. The method of claim 1 or 2, wherein said second antigen recognition portion comprises a nucleic acid.
- 10 21. The method of claim 1 or 2, wherein said N-intein first antigen recognition portion is produced recombinantly.
22. The method of claim 1 or 2, wherein said C-intein second  
15 antigen recognition portion is produced recombinantly.
23. The method of claim 1 or 2, wherein said C-intein second antigen recognition portion is produced by peptide synthesis.
- 20 24. The method of claim 1 or 2, wherein N-intein first antigen recognition portion and said C-intein second antigen recognition portion are recombinantly co-expressed in a cell, and wherein said N-intein first antigen recognition portion and said C-intein second antigen recognition portion  
25 reconstitute and undergo trans-splicing in said cell to produce said bispecific molecule.
25. The method of claim 1 or 2, wherein said N-intein first antigen recognition portion is recombinantly expressed in a first cell and said C-intein second antigen recognition  
30 portion is recombinantly expressed in a second cell, and wherein said N-intein first antigen recognition portion and said C-intein second antigen recognition portion are mixed in vitro to produce said bispecific molecule.
- 35 26. The method of claim 25, wherein said N-intein first antigen recognition portion and said C-intein second antigen

recognition portion are expressed by separate expression vectors.

27. The method of claim 25, wherein said N-intein first  
5 antigen recognition portion and said C-intein second antigen  
recognition portion are expressed by one expression vector.

28. The method of claim 15, wherein the heavy and light  
chains of said anti-CR1 mAb are recombinantly expressed using  
10 same vector.

29. The method of claim 15, wherein the heavy and light  
chains of said anti-CR1 mAb are recombinantly expressed using  
separate vectors.

15 30. The method of claim 29, wherein said heavy and light  
chains of said anti-CR1 mAb are recombinantly expressed in  
same cell.

20 31. The method of claim 29, wherein said heavy and light  
chains of said anti-CR1 mAb are recombinantly expressed in  
separate cells using separate vectors, and wherein said heavy  
and light chains are assembled into said mAb in vitro.

25 32. A method of producing a bispecific molecule having a  
first antigen recognition portion that binds a C3b-like  
receptor and a second antigen recognition portion that binds  
a pathogenic antigenic molecule, comprising

(a) contacting an N-intein first antigen recognition  
portion and a C-intein streptavidin under conditions such  
30 that trans-splicing occurs to produce a first antigen  
recognition portion-streptavidin molecule, wherein said N-  
intein first antigen recognition portion comprises said first  
antigen recognition portion conjugated to the amino terminus  
of an N-intein of a split intein, and wherein said C-intein  
35 streptavidin comprises a core streptavidin conjugated to the  
carboxy terminus of a C-intein of said split intein, wherein

the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine; and

- 5 (b) contacting said first antigen recognition portion-streptavidin molecule and a biotinylated second antigen recognition portion under conditions conducive to binding between streptavidin and biotin, to produce said bispecific molecule.

10 33. A method of producing a bispecific molecule having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, comprising:

- 15 (a) obtaining an N-intein first antigen recognition portion by conjugating said first antigen recognition portion to the amino terminus of an N-intein of a split intein;

(b) obtaining a C-intein streptavidin by conjugating a core streptavidin to the carboxy terminus of the C-intein of said split intein, wherein the amino acid  
20 residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine;

(c) contacting said N-intein first antigen recognition portion and said C-intein streptavidin under  
25 conditions such that protein trans-splicing occurs, to produce a first antigen recognition portion-streptavidin molecule, wherein said first antigen recognition portion is conjugated to said streptavidin;

(d) obtaining a biotinylated second antigen  
30 recognition portion; and

(e) contacting said first antigen recognition portion-streptavidin molecule and said biotinylated second antigen recognition portion under conditions conducive to binding between streptavidin and biotin, to produce said  
35 bispecific molecule.

34. The method of claim 32 or 33, wherein said C-intein streptavidin is generated recombinantly.

35. The method of claim 34, further comprising in step (b)  
5 the step of dissociating multimers of C-intein streptavidin.

36. The method of claim 32 or 33, wherein said biotinylated second antigen recognition portion is a biotinylated monoclonal antibody.

10 37. The method of claim 32 or 33, wherein said biotinylated second antigen recognition portion is produced by biotinylating of an antibody.

15 38. The method of claim 36, wherein said biotinylated monoclonal antibody is biotinylated at a single site.

39. The method of claim 36, wherein said biotinylated monoclonal antibody is biotinylated at a site such that the antigen binding capability of the antigen recognition domain  
20 is not impaired.

40. The method of claim 32 or 33, wherein said biotinylated second antigen recognition portion is a biotinylated nucleic acid.  
25

41. The method of claim 40, wherein said biotinylated nucleic acid is produced from a nucleic acid sample by  
(a) amplifying said nucleic acid using a PCR primer containing a restriction digestion site for a restriction  
30 endonuclease wherein said restriction endonuclease generates an overhanging terminus upon cleavage at said restriction digestion site, and said restriction endonuclease does not cleave said nucleic acid other than within the sequence of said PCR primer;

35



(b) cleaving the PCR product containing said PCR primer by said restriction endonuclease to generate an overhanging terminus; and

(c) adding a biotinylated nucleotide at said  
5 overhanging terminus using a DNA polymerase to produce said biotinylated nucleic acid.

42. A method of producing a polyclonal library of bispecific molecules, each member of said polyclonal library having a  
10 first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, comprising contacting a plurality of N-intein first antigen recognition portions and a plurality of different C-intein second antigen recognition  
15 portions under conditions such that protein trans-splicing occurs to produce a polyclonal library of bispecific molecules, wherein each of said plurality of N-intein first antigen recognition portions comprises said first antigen recognition portion conjugated to the amino terminus of an N-intein of a split intein, and wherein each of said plurality  
20 of C-intein second antigen recognition portions comprises a second antigen recognition portion having a different binding specificity conjugated to the carboxy terminus of a C-intein of said split intein, wherein the amino acid residue immediately at the C-terminal side of the splice junction of  
25 said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

43. A method of producing a polyclonal library of bispecific molecules, each member of said polyclonal library having a  
30 first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, comprising:

(a) obtaining a plurality of N-intein first antigen recognition portions by a method comprising conjugating each  
35 of a plurality of first antigen recognition portions to the amino terminus of an N-intein of a split intein;

(b) selecting from a phage display library a plurality of phage that display antigen recognition polypeptides, each having a different respective binding specificity using affinity screening;

5 (c) obtaining a plurality of nucleic acids encoding said plurality of antigen recognition polypeptides, respectively;

(d) fusing each nucleic acid of said plurality of nucleic acids to the amino terminus of a C-intein of said  
10 split intein to obtain a plurality of nucleic acids encoding a plurality of C-intein antigen recognition portions, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and  
15 threonine;

(e) expressing said plurality of nucleic acids encoding said plurality of C-intein antigen recognition portion fragments in a host;

(f) obtaining said plurality of C-intein antigen recognition portions from said host; and  
20

(g) contacting said plurality of C-intein antigen recognition portions and a plurality of said N-intein first antigen recognition portions under conditions such that protein trans-splicing occurs, to produce said polyclonal library of bispecific molecules.  
25

44. A method of producing a polyclonal library of bispecific molecules, each member of said polyclonal library having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds  
30 a pathogenic antigenic molecule, comprising:

(a) obtaining a plurality of N-intein first antigen recognition portions by a method comprising conjugating each of a plurality of first antigen recognition portions to the amino terminus of an N-intein of a split intein;  
35

(b) fusing the amino terminus of the nucleic acid encoding a polypeptide antibody in each member of said phage

display library to the carboxy terminus of a C-intein of said split intein to obtain a phage display library displaying a repertoire of C-intein antigen recognition portions, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine;

(c) selecting from said phage display library displaying a repertoire of C-intein antigen recognition portions a plurality of phage that display C-intein antigen recognition portions, each having a different respective binding specificity using affinity screening;

(d) obtaining a plurality of nucleic acids encoding said plurality of C-intein antigen recognition portions, respectively;

(e) expressing said plurality of nucleic acids encoding said plurality of C-intein antigen recognition portions in a host;

(g) obtaining said plurality of C-intein antigen recognition portions from said host; and

(h) contacting said plurality of C-intein antigen recognition portions and a plurality of said N-intein first antigen recognition portions under conditions such that protein trans-splicing occurs, to produce said polyclonal library of bispecific molecules.

45. A method of producing a polyclonal library of bispecific molecules, each member of said polyclonal library having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, comprising

(a) contacting a population of N-intein first antigen recognition portions and a population of C-intein streptavidin under conditions such that protein trans-splicing occurs to produce a population of first antigen recognition portion-streptavidin molecules, wherein each of said plurality of N-intein first antigen recognition portions

comprises said first antigen recognition portion conjugated to the amino terminus of an N-intein of a split intein, and wherein each of said plurality of C-intein streptavidin comprises a core streptavidin conjugated to the carboxy  
5 terminus of a C-intein of said split intein, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine; and

10 (b) contacting said population of first antigen recognition portion streptavidin molecule and a plurality of biotinylated second antigen recognition portions, each having a different antigen recognition specificity under conditions conducive to binding between streptavidin and biotin, to  
15 produce said polyclonal library of bispecific molecules.

46. A method of producing a polyclonal library of bispecific molecules, each member of said polyclonal library having a first antigen recognition portion that binds a C3b-like  
20 receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, comprising:

(a) obtaining a population of N-intein first antigen recognition portions by a method comprising conjugating each of a population of first antigen recognition portions to the amino terminus of an N-intein of a split  
25 intein;

(b) obtaining a population of C-intein streptavidin by a method comprising conjugating each of a population of core streptavidins to a C-intein of said split intein, wherein the amino acid residue immediately at the C-terminal  
30 side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine;

(c) contacting said population of N-intein first antigen recognition portions with said population of C-intein  
35 streptavidins under conditions such that protein trans-

splicing occurs to produce a population of first antigen recognition portion streptavidin molecules;

- (d) selecting from a phage display library a plurality of phage that display antigen recognition polypeptides, each having a different respective binding specificity using affinity screening;
- (f) obtaining a plurality of nucleic acids encoding said plurality of antigen recognition polypeptides, respectively;
- (g) expressing said plurality of nucleic acids encoding said plurality of antigen recognition polypeptides in a host;
- (h) obtaining said plurality of antigen recognition polypeptides from said host;
- (i) obtaining a plurality of biotinylated antigen recognition polypeptides by conjugating each member of said plurality of antigen recognition polypeptides with biotin using an activated biotin agent; and
- (j) contacting said plurality of biotinylated antigen recognition polypeptides and said population of first antigen recognition portion streptavidin molecules under conditions conducive to binding between streptavidin and biotin, to produce said polyclonal library of bispecific molecules.

47. The method of claim 42, 43, 44, 45, or 46, wherein said plurality of antigen recognition portions has binding specificities for a plurality of epitopes of an antigen.

48. The method of claim 42, 43, 44, 45, or 46, wherein said plurality of antigen recognition portions has binding specificities for a plurality of variants of an antigen.

49. The method of claim 43 or 46, wherein said plurality of nucleic acids encoding said plurality of antigen recognition polypeptides is fused to said C-intein without clonal isolation.

50. The method of claim 43 or 46, wherein step (a) further comprising obtaining a plurality of different N-intein first antigen recognition portions by conjugating each of a plurality of different first antigen recognition portions to the amino terminus of a plurality of N-inteins of said split intein.

51. A method of producing a C-intein antigen recognition portion phage display library, each phage in said C-intein antigen recognition portion phage display library displaying on its surface a different C-intein antigen recognition portion, comprising fusing the amino terminus of the nucleic acid encoding a polypeptide antibody in each of a plurality of members of a phage display library to the carboxy terminus of a C-intein of a split intein to obtain a phage display library displaying a repertoire of C-intein antigen recognition portions, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

52. A bispecific molecule, comprising:

(a) a first antigen recognition portion that binds a C3b-like receptor; and

(b) a second antigen recognition portion that binds a pathogenic antigenic molecule;

wherein said first antigen recognition portion comprises a monoclonal antibody, and wherein said second antigen recognition portion is conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion.

53. A bispecific molecule, comprising:

(a) a first antigen recognition portion that binds a C3b-like receptor;

(b) a linker; and

(c) a second antigen recognition portion that binds a pathogenic antigenic molecule;  
wherein said second antigen recognition portion is conjugated to a carboxy terminus of said first antigen recognition  
5 portion via said linker.

54. The bispecific molecule of claim 53, wherein said linker is a peptide linker.

10 55. The bispecific molecule of claim 53, wherein said linker is a streptavidin-biotin linker.

56. The bispecific molecule of claim 53, wherein said linker is a Poly(ethylene glycol) linker.

15 57. The bispecific molecule of claim 53, wherein said first antigen recognition portion comprises an antigen binding domain that binds a C3b-like receptor on a mammalian blood cell and an effector domain that facilitates transfer of said  
20 pathogenic antigenic molecule from said mammalian blood cell to a phagocytic cell.

58. The bispecific molecule of claim 53, wherein said first antigen recognition portion is a monoclonal antibody.

25 59. The bispecific molecule of claim 52 or 58, wherein said second antigen recognition portion is conjugated to the C-terminus of a heavy chain of said first antigen recognition portion.

30 60. The bispecific molecule of claim 52 or 58, wherein said second antigen recognition portion is conjugated to the C-terminus of a light chain of said first antigen recognition portion.

35 61. The bispecific molecule of claim 52 or 58, wherein said second antigen recognition portion comprises two antigen

recognition moieties each conjugated to the C-terminus of a different heavy chain of said first antigen recognition portion.

5 62. The bispecific molecule of claim 52 or 58, wherein said first antigen recognition portion is an anti-CR1 monoclonal antibody produced by the hybridoma cell line ATCC HB 8592 from the American Type Culture Collection (ATCC), and wherein the second antigen recognition portion comprises the  $\alpha$ -  
10 subunit of Fc $\epsilon$ RI receptor.

63. The bispecific molecule of claim 52 or 58, wherein said second antigen recognition portion comprises two antigen recognition moieties each conjugated to the C-terminus of a  
15 different light chain of said first antigen recognition portion.

64. The bispecific molecule of claim 61, wherein said two antigen recognition moieties are the same antigen recognition  
20 moieties.

65. The bispecific molecule of claim 61, wherein said two antigen recognition moieties are different antigen recognition moieties.

25 66. The bispecific molecule of claim 65, wherein said different antigen recognition moieties target said pathogenic antigen cooperatively.

30 67. The bispecific molecule of claim 65, wherein the action of one of said different antigen recognition moieties enhances the binding affinity of the other one of said different antigen recognition moieties.

35 68. The bispecific molecule of claim 52 or 53, wherein said second antigen recognition portion comprises a peptide or polypeptide.



69. The bispecific molecule of claim 68, wherein said peptide or polypeptide is an antibody.

70. The bispecific molecule of claim 69, wherein said  
5 peptide or polypeptide is an monoclonal antibody.

71. The bispecific molecule of claim 68, wherein said peptide or polypeptide comprises an epitope.

10 72. The bispecific molecule of claim 52 or 53, wherein said second antigen recognition portion comprises a nucleic acid.

73. A polyclonal library of bispecific molecules comprising a plurality of bispecific molecules each comprising (a) a  
15 first antigen recognition portion that binds a C3b-like receptor, and (b) a different second antigen recognition portion, said different second antigen recognition portions having different binding specificities, wherein said first  
antigen recognition portion comprises a monoclonal antibody, and wherein said second antigen recognition portion is  
20 conjugated to a carboxy terminus of said first antigen recognition portion.

74. A polyclonal library of bispecific molecules comprising a plurality of bispecific molecules, each comprising:  
25 (a) a first antigen recognition portion that binds a C3b-like receptor;  
(b) a linker; and  
(c) a different second antigen recognition portion having a different binding specificity;  
30 wherein said second antigen recognition portion is conjugated to a carboxy terminus of said first antigen recognition portion via said linker.

75. The bispecific molecule of claim 74, wherein said linker  
35 is a peptide linker.

76. The bispecific molecule of claim 74, wherein said linker is a streptavidin-biotin linker.

77. The bispecific molecule of claim 74, wherein said linker  
5 is a Poly (ethylene glycol) linker.

78. The polyclonal library of bispecific molecules of claim 74, wherein the first antigen recognition portion of each bispecific molecule comprises an antigen binding domain that  
10 binds a C3b-like receptor on mammalian blood cell and an effector domain that facilitates transfer of said pathogenic antigenic molecule from said mammalian blood cell to a phagocytic cell.

79. The polyclonal library of bispecific molecules of claim  
15 74, wherein the first antigen recognition portion of each bispecific molecule is a monoclonal antibody.

80. The polyclonal library of bispecific molecules of claim  
20 73 or 79, wherein for each bispecific molecule said second antigen recognition portion is conjugated to the C-terminus of a heavy chain of said first antigen recognition portion.

81. The polyclonal library of bispecific molecules of claim  
25 73 or 79, wherein for each bispecific molecule said second antigen recognition portion is conjugated to the C-terminus of a light chain of said first antigen recognition portion.

82. The polyclonal library of bispecific molecules of claim  
30 73 or 79, wherein for each bispecific molecule said second antigen recognition portion comprises two antigen recognition moieties each conjugated to the C-terminus of a different heavy chain of said first antigen recognition portion.

83. The polyclonal library of bispecific molecules of claim  
35 73 or 79, wherein for each bispecific molecule said second antigen recognition portion comprises two antigen recognition

moieties each conjugated to the C-terminus of a different light chain of said first antigen recognition portion.

84. The polyclonal library of bispecific molecules of claim  
5 82, wherein said two antigen recognition moieties are same antigen recognition moieties.

85. The polyclonal library of bispecific molecules of claim  
82, wherein said two antigen recognition moieties are  
10 different antigen recognition moieties.

86. The polyclonal library of bispecific molecules of claim  
85, wherein for each bispecific molecule said different  
antigen recognition moieties target said pathogenic antigen  
15 cooperatively.

87. The polyclonal library of bispecific molecules of claim  
85, wherein the action of one of said different antigen  
recognition moieties enhances the binding affinity of the  
other one of said different antigen recognition moieties.  
20

88. The polyclonal library of bispecific molecules of claim  
73 or 74, wherein for each bispecific molecule said second  
antigen recognition portion comprises a peptide or  
polypeptide.  
25

89. The polyclonal library of bispecific molecules of claim  
88, wherein for each bispecific molecule said peptide or  
polypeptide is an antibody.

30 90. The polyclonal library of bispecific molecules of claim  
88, wherein said peptide or polypeptide is an monoclonal  
antibody.

91. The polyclonal library of bispecific molecules of claim  
35 88, wherein said peptide or polypeptide comprises an epitope.

92. The polyclonal library of bispecific molecules of claim 73 or 74, wherein for each bispecific molecule said second antigen recognition portion comprises a nucleic acid.

5 93. A composition comprising a plurality of purified bispecific molecules, wherein each bispecific molecule of said plurality of purified bispecific molecules comprises a first antigen recognition portion that binds a C3b-like  
10 a pathogenic antigenic molecule, wherein said first antigen recognition portion comprises a monoclonal antibody, and wherein said second antigen recognition portion is conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion, said plurality of purified  
15 bispecific molecules each comprising a different second antigen recognition portions that has a different binding specificity.

94. A composition comprising a plurality of purified bispecific molecules, wherein each bispecific molecule of  
20 said plurality of purified bispecific molecules comprises:  
    (a) a first antigen recognition portion that binds a C3b-like receptor; and  
    (b) a second antigen recognition portion that binds a pathogenic antigenic molecule;  
25 wherein said first antigen recognition portion comprises a monoclonal antibody, and wherein said second antigen recognition portion is conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition  
30 portion, said plurality of purified bispecific molecules each comprising a different second antigen recognition portions that has a different binding specificity.

95. A molecule, comprising:  
    (a) an antigen recognition portion that binds a  
35 C3b-like receptor; and

(b) an N-intein moiety comprising an N-intein of a split intein;  
wherein said antigen recognition portion is conjugated to the amino terminal end of said N-intein moiety.

5

96. The molecule of claim 95, wherein said antigen recognition portion is conjugated to said N-intein via a linker.

10 97. The molecule of claim 95, wherein said N-intein moiety is an N-intein.

98. The molecule of claim 95 or 96, wherein said antigen recognition portion is a monoclonal antibody.

15

99. The molecule of claim 95 or 96, wherein said antigen recognition portion is an ScFv fused to an Fc domain.

20

100. The molecule of claim 95 or 96, wherein said antigen recognition portion is a chimeric antibody comprising variable domains or complementarity determining regions (CDRs) from one species and constant domain from another species.

25

101. The molecule of claim 100, wherein said variable domains or complementarity determining regions (CDRs) are murine and said constant domain is human.

30

102. The molecule of claim 95 or 96, wherein said N-intein further comprises a sequence of 1 or more native proximal N-extein amino acid residue.

35

103. The molecule of claim 102, wherein said N-intein comprises a sequence of 3 to 5 native proximal N-extein amino acid residue.

104. The molecule of claim 95 or 96, wherein said N-intein comprises at the N-terminus an O-(2-nitrobenzyl)serine.

105. The molecule of claim 95 or 96, wherein said N-intein is  
5 the N-intein of the split intein encoded in the DnaE gene of Ssp.

106. The molecule of claim 102, wherein said N-intein is the N-intein of the split intein encoded in the DnaE gene of Ssp.

10  
107. The molecule of claim 105, wherein said antigen recognition portion is a monoclonal antibody as produced by the hybridoma cell line ATCC HB 8592 from the American Type Culture Collection (ATCC).

15  
108. The molecule of claim 106, wherein said antigen recognition portion is a monoclonal antibody as produced by the hybridoma cell line ATCC HB 8592 from the American Type Culture Collection (ATCC).

20  
109. The molecule of claim 95 or 96, wherein said N-intein is the N-intein of an engineered split intein generated from the Mtu RecA intein.

110. A molecule, comprising:

- 25           (a) an antigen recognition portion; and  
            (b) a C-intein moiety comprising a C-intein of a split intein;

          wherein said antigen recognition portion is conjugated to the carboxy terminal end of said C-intein moiety, and wherein the  
30 amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

35

111. The molecule of claim 110, wherein said antigen recognition portion is conjugated to said C-intein via a linker.
- 5 112. The molecule of claim 110, wherein said C-intein moiety is a C-intein.
113. The molecule of claim 110 or 111, wherein said antigen recognition portion comprises a peptide or polypeptide.
- 10 114. The molecule of claim 110 or 111, wherein said antigen recognition portion comprises a nucleic acid.
115. The molecule of claim 110 or 111, wherein said C-intein  
15 further comprises, after said amino acid residue selected from the group consisting of cysteine, serine, and threonine, a sequence of 1 or more native proximal C-extein amino acid residues.
- 20 116. The molecule of claim 113, wherein said C-intein comprises, after said amino acid residue selected from the group consisting of cysteine, serine, and threonine, a sequence of 3 to 5 native proximal C-extein amino acid residues.
- 25 117. The molecule of claim 110 or 111, wherein said C-intein is the C-intein of the split intein encoded in the DnaE gene of Ssp.
- 30 118. The molecule of claim 115, wherein said C-intein is the C-intein of the split intein encoded in the DnaE gene of Ssp.
119. The C-intein antigen recognition portion of claim 117, wherein said antigen recognition portion comprises the  $\alpha$ -  
35 subunit of the Fc $\epsilon$ RI receptor.

120. The molecule of claim 110 or 111, wherein said C-intein is the C-intein of an engineered split intein generated from the Mtu RecA intein.

5 121. The molecule of claim 115, wherein said C-intein is the C-intein of an engineered split intein generated from the Mtu RecA intein.

122. A molecule, comprising:

10 (a) a streptavidin; and  
(b) a C-intein of a split intein comprising, immediately at the C-terminal side of the splice junction, an amino acid residue selected from the group consisting of cysteine, serine, and threonine;  
15 wherein said streptavidin is conjugated to the carboxy terminus of said C-intein.

123. The molecule of claim 122, wherein said streptavidin is conjugated to said C-intein via a linker.

20 124. The molecule of claim 122 or 123, wherein said C-intein further comprises a sequence of 1 or more native proximal C-extein amino acid residues.

25 125. The molecule of claim 124, wherein said C-intein further comprises a sequence of 3 to 5 native proximal C-extein amino acid residues.

126. The molecule of claim 122 or 123, wherein said C-intein is the C-intein of the split intein encoded in the DnaE gene  
30 of Ssp.

127. The molecule of claim 124, wherein said C-intein is the C-intein of the split intein encoded in the DnaE gene of Ssp.

35



128. The molecule of claim 122 or 123, wherein said C-intein is the C-intein of an engineered split intein generated from the Mtu RecA intein.

5 129. A C-intein antigen recognition portion phage display library, comprising a plurality of phage, each phage in said plurality displaying on its surface a different C-intein polypeptide fusion protein, wherein each polypeptide has a different binding specificity.

10 130. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of the N-intein  
15 of a split intein.

131. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding a second antigen recognition portion fused to the  
20 carboxy terminus of a C-intein of a split intein wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

25 132. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding a core streptavidin fused to the carboxy terminus of a C-intein of a split intein wherein the amino acid residue immediately at the C-terminal side of the splice junction of  
30 said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

133. A nucleic acid encoding an N-intein fused to the carboxy terminus of a heavy chain of an anti-CR1 monoclonal antibody.  
35

134. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding an N-intein fused to the carboxy terminus of a heavy chain of an anti-CR1 monoclonal antibody.
- 5 135. A nucleic acid encoding an N-intein fused to the carboxy terminus of the light chain of an anti-CR1 monoclonal antibody.
- 10 136. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding an N-intein fused to the carboxy terminus of a light chain of an anti-CR1 monoclonal antibody.
- 15 137. The nucleic acid of claim 133 or 135, wherein said N-intein is the N-intein of the split intein encoded in the DnaE gene of Ssp.
- 20 138. The nucleic acid of claim 133 or 135, wherein said N-intein is the N-intein of an engineered split intein generated from the Mtu RecA intein.
- 25 139. The nucleic acid of claim 133 or 135, wherein said anti-CR1 monoclonal antibody is as produced by the hybridoma cell line ATCC HB 8592 from the American Type Culture Collection (ATCC).
140. A nucleic acid encoding an N-intein fused to the carboxy terminus of the Fc domain that is fused to a scFv.
- 30 141. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding an N-intein fused to the carboxy terminus of the Fc domain that is fused to a scFv.
- 35 142. A nucleic acid encoding a C-intein fused to the amino terminus of a polypeptide that binds an antigen.

143. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding a C-intein fused to the amino terminus of polypeptide that binds an antigen.
- 5 144. A nucleic acid encoding a C-intein fused to the amino terminus of a core streptavidin via an optional linker.
- 10 145. An expression vector, comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding a C-intein fused to the amino terminus of core streptavidin via an optional linker.
- 15 146. A plurality of nucleic acids encoding a plurality of C-intein antigen recognition portions.
- 20 147. A plurality of expression vectors, each comprising a transcriptional regulatory element operably linked to a nucleotide sequence encoding a C-intein antigen recognition portion.
- 25 148. A kit comprising in a container a bispecific molecule having a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds a pathogenic antigenic molecule, wherein said first antigen recognition portion comprises a monoclonal antibody, and wherein said second antigen recognition portion is conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion.
- 30 149. A kit comprising in a container a bispecific molecule comprising:
- (a) a first antigen recognition portion that binds a C3b-like receptor;
  - (b) a linker; and
  - 35 (c) a second antigen recognition portion that binds a pathogenic antigenic molecule;

wherein said second antigen recognition portion is conjugated to a carboxy terminus of said first antigen recognition portion via said linker.

5 150. A kit comprising in a container a molecule comprising:

- (a) an antigen recognition portion that binds a C3b-like receptor; and
- (b) an N-intein moiety comprising an N-intein of a split intein;

10 wherein said antigen recognition portion is conjugated to the amino terminal end of said N-intein moiety.

151. A kit comprising in a container a molecule comprising:

- (a) an antigen recognition portion; and
- 15 (b) a C-intein moiety comprising a C-intein of a split intein;

wherein said antigen recognition portion is conjugated to the carboxy terminal end of said C-intein moiety, and wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue  
20 selected from the group consisting of cysteine, serine, and threonine.

152. A kit comprising in two containers a first molecule comprising an antigen recognition portion that binds a C3b-  
25 like receptor and an N-intein moiety comprising an N-intein of a split intein, wherein said antigen recognition portion is conjugated to the amino terminal end of said N-intein moiety; and a second molecule comprising an antigen recognition portion and a C-intein moiety comprising a C-  
30 intein of a split intein, wherein said antigen recognition portion is conjugated to the carboxy terminal end of said C-intein peptide, and wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the  
35 group consisting of cysteine, serine, and threonine.

153. A kit comprising in one or more containers a first vector and a second vector, said first vector comprising a first DNA sequence encoding a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of an N-intein peptide comprising an N-intein of a split intein, said second vector comprising a second DNA sequence encoding a second antigen recognition portion fused to the carboxy terminus of a C-intein peptide comprising a C-intein of said split intein, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein peptide is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

154. A kit comprising in one or more containers a first vector and a second vector, said first vector comprising a first DNA sequence encoding a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of an N-intein peptide comprising an N-intein of a split intein, said second vector comprising a second DNA sequence encoding a core streptavidin fused to the carboxy terminus of a C-intein peptide comprising a C-intein of said split intein wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein peptide is an amino acid residue selected from the group consisting of cysteine, serine, and threonine, and in a separate container a biotinylated second antigen recognition portion.

155. A kit comprising a phage display library, wherein each phage displays a different C-intein polypeptide fusion protein on its surface.

156. The kit of claim 153 or 154, wherein said first vector further comprises a first promoter operably linked to said first DNA sequence, and said second vector further comprises a second promoter operably linked to said second DNA sequence.

157. A cell transformed with a vector comprising a DNA sequence encoding a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of the N-intein of a split intein.

5

158. A cell transformed with a vector comprising a DNA sequence encoding a second antigen recognition portion fused to the carboxy terminus of a C-intein of a split intein wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

10

159. A cell transformed with a vector comprising a DNA sequence encoding a core streptavidin fused to the carboxy terminus of a C-intein of a split intein wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

15

160. A cell transformed with a first vector and a second vector, said first vector comprising a first DNA sequence encoding a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of an N-intein of a split intein, said second vector comprising a second DNA sequence encoding a second antigen recognition portion fused to the carboxy terminus of a C-intein of said split intein wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

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161. A cell containing a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of the N-intein of a split intein.

35

162. A cell containing a second antigen recognition portion fused to the carboxy terminus of a C-intein of a split intein, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

163. A cell containing a first antigen recognition portion that binds a C3b-like receptor fused to the amino terminus of an N-intein of a split intein and a second antigen recognition portion fused to the carboxy terminus of a C-intein of said split intein, wherein the amino acid residue immediately at the C-terminal side of the splice junction of said C-intein is an amino acid residue selected from the group consisting of cysteine, serine, and threonine.

164. A method of treating a mammal having a disease or disorder or undesirable condition associated with the presence of a pathogen or pathogenic antigenic molecule, comprising administering to said mammal a therapeutically effective dose of a bispecific molecule comprising:

(a) a first antigen recognition portion that binds a C3b-like receptor, said first antigen recognition portion comprising a monoclonal antibody; and

(b) a second antigen recognition portion that binds an epitope of said pathogen or pathogenic antigenic molecule, said second antigen recognition portion being conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion.

165. A method of preventing a disease or disorder or undesirable condition associated with the presence of a pathogen or pathogenic antigenic molecule in a mammal, comprising administering to said mammal a therapeutically effective dose of a bispecific molecule comprising:

(a) a first antigen recognition portion that binds a C3b-like receptor, said first antigen recognition portion comprising a monoclonal antibody; and

(b) a second antigen recognition portion that binds  
5 an epitope of said pathogen or pathogenic antigenic molecule, said second antigen recognition portion being conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion.

10 166. The method of claim 164 or 165, wherein said second antigen recognition portion is conjugated to the C-terminus of a heavy chain of said first antigen recognition portion.

15 167. The method of claim 164 or 165, wherein said second antigen recognition portion is conjugated to the C-terminus of a light chain of said first antigen recognition portion.

168. The method of claim 164 or 165, wherein said second antigen recognition portion comprises two antigen recognition  
20 moieties each conjugated to the C-terminus of a different heavy chain of said first antigen recognition portion.

169. The method of claim 164 or 165, wherein said administering is intravenous.

25 170. The method of claim 164 or 165, wherein said mammal is a human, and said C3b-like receptor is CR1.

171. The method of claim 164 or 165, wherein said mammal is a non-human mammal.

30

172. The method of claim 170, wherein said pathogen is an autoimmune antigen.

173. The method of claim 170, wherein said pathogen is an  
35 infectious agent.



174. The method of claim 173, wherein said infectious agent is a virus.

175. The method of claim 174, wherein said virus is HIV-1  
5 virus.

176. The method of claim 173, wherein said infectious agent is a bacterium.

10 177. The method of claim 176, wherein said bacterium is Bacillus anthracis.

178. The method of claim 173, wherein said infectious agent is a fungus.

15 179. The method of claim 173, wherein said infectious agent is a parasite.

180. The method of claim 179, wherein said parasite is a  
20 protozoan.

181. The method of claim 170, wherein said pathogenic antigenic molecule is a toxin.

25 182. A method of treating a mammal having an undesirable condition associated with the presence of a pathogen or pathogenic antigenic molecule comprising the steps of:

(a) contacting a bispecific molecule with hematopoietic cells expressing a C3b-like receptor, to form a hematopoietic cell/bispecific molecule complex,  
30 wherein the bispecific molecule comprises (i) a first antigen recognition portion that binds said C3b-like receptor, said first antigen recognition portion comprising a monoclonal antibody; and (ii)  
35 a second antigen recognition portion that binds an epitope of said pathogen or pathogenic antigenic molecule, said second antigen recognition portion

being conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion; and

- 5 (b) administering said hematopoietic cell/bispecific molecule complex to said mammal in a therapeutically effective amount.

183. A method of treating a mammal having an undesirable condition associated with the presence of a pathogen or  
10 pathogenic antigenic molecule, comprising the step of administering a therapeutically effective amount of a hematopoietic cell/bispecific molecule complex to said mammal, said complex consisting essentially of a hematopoietic cell expressing a C3b-like receptor bound to  
15 one or more bispecific molecules, wherein said bispecific molecule comprises (a) a first antigen recognition portion that binds said C3b-like receptor, said first antigen recognition portion comprising a monoclonal antibody; and (b) a second antigen recognition portion that binds an epitope of  
20 said pathogen or pathogenic antigenic molecule, said second antigen recognition portion being conjugated to a carboxy terminus of a heavy or light chain of said first antigen recognition portion.

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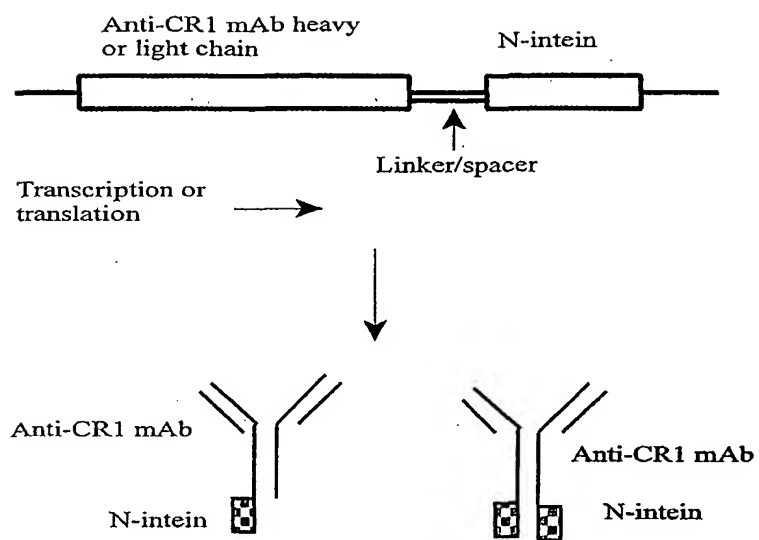


FIG. 1a

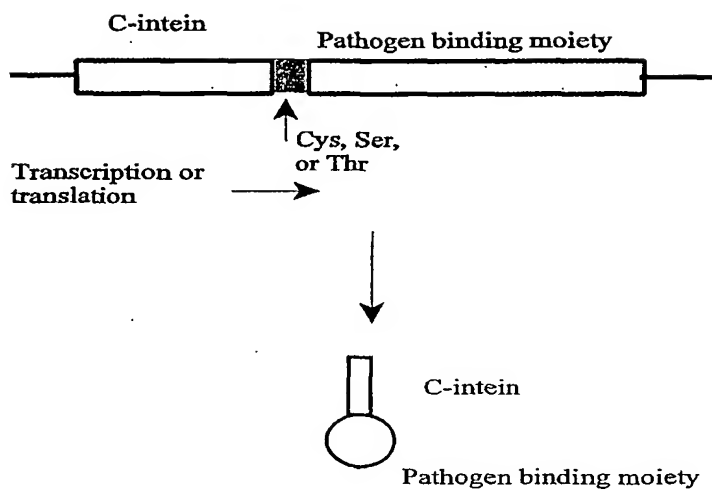


FIG. 1b

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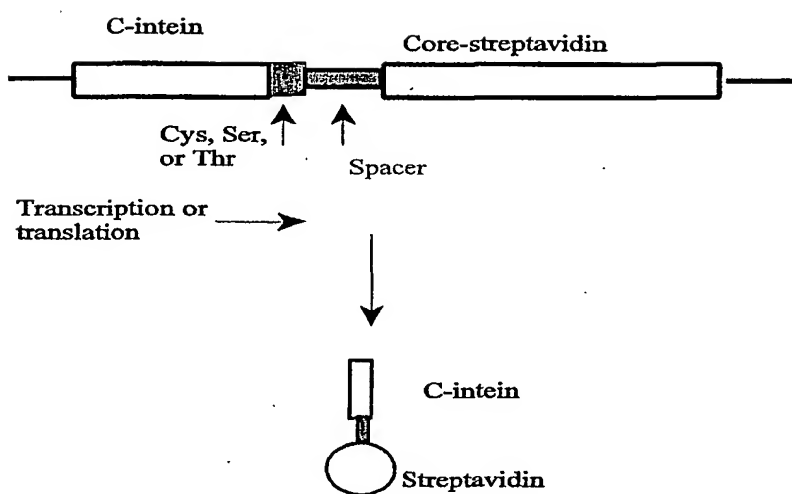


FIG. 1c

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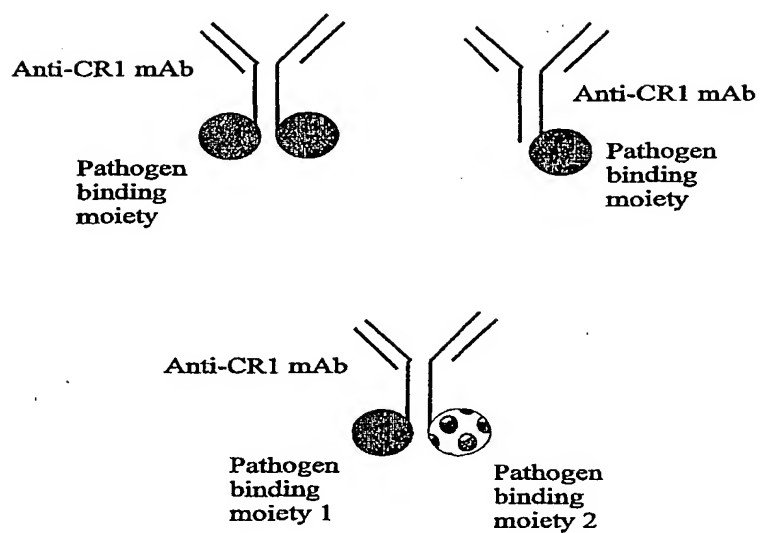


FIG. 1d

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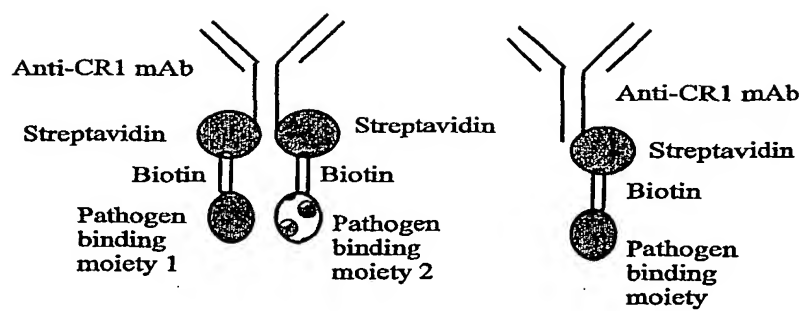


FIG. 1e

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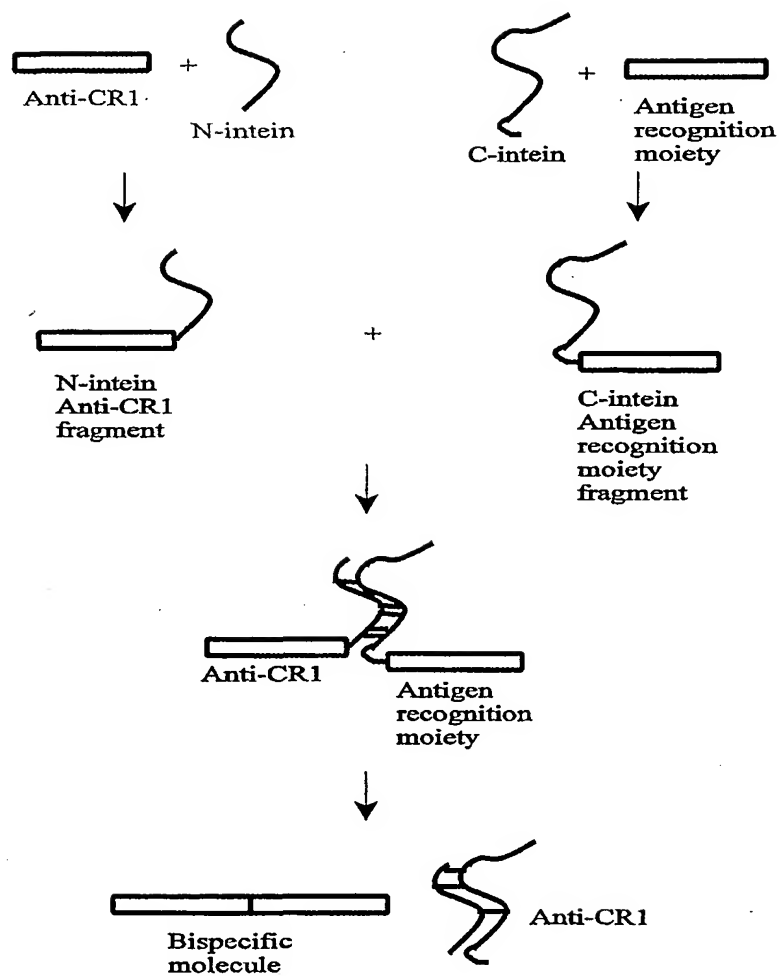


FIG. 2

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CLSFGTEILTVEYGPLPIGKIVSEEINCSVYSVDPEGRVYTQAIQWHDGRGEQEVLEYELED  
GSVIRATSDHRFLTTYQLLAIEEIFARQLDLLTLENIKQTEEALDNHRLPFPLLDAGTIK

**FIG. 3a**

MVKVIGRRSLGVQRIFDIGLPQDHNFLLANGAIAANC

**FIG. 3b**

FDQMVKFAEY

**FIG. 3c**

CFNKSHSTAY

**FIG. 3d**

**FIG. 3**

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- (75) Inventor/Applicant (for US only): HIMAWAN, Jeff [US/US]; 9654 Gretna Green Drive, Westchase Complex, Tampa, FL 33626-5310 (US).
- (74) Agents: ANTLEER, Adriane, M. et al.; Pennie & Edmonds LLP, 1155 Avenue of the Americas, New York, NY 10036 (US).
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(54) Title: METHOD OF PRODUCING BIOSPECIFIC MOLECULES BY PROTEIN TRANS-SPLICING

(57) Abstract: The invention provides methods of using protein trans-splicing for the production of bispecific molecule which has a first antigen recognition portion that binds a C3b-like receptor and a second antigen recognition portion that binds an antigenic molecule present in the circulatory system of a mammal. The invention also provides bispecific molecules produced by protein trans-splicing. The bispecific molecules of the invention can be used for the clearance of pathogenic antigenic molecules from the circulatory system of a mammal. The invention further provides methods of using protein trans-splicing for the production of polyclonal libraries of bispecific molecules, which comprise populations of bispecific molecules with different antigen recognition specificities. Such polyclonal libraries of bispecific molecules can be used for targeting multiple epitopes of a pathogenic antigenic molecule and/or multiple variants of a pathogenic antigenic molecule.

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/45653

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : A61K 39/395, 48/00; C12P 21/06; C12N 9/00  
US CL : 435/68.1, 69.1, 69.7, 183; 424/142.1, 143.1, 147.1, 136.1, 150.1, 178.1; 530/333, 388.3, 388.4; 422/61; 604/507

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/68.1, 69.1, 69.7, 183; 424/142.1, 143.1, 147.1, 136.1, 150.1, 178.1; 530/333, 388.3, 388.4; 422/61; 604/507.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SCOTT, P. C. et al. Production of cyclic peptides and proteins in vivo. Proc. Natl. Acad. Sci. U.S.A. (1999) Vol. 96, pages 13638-13643. Entire document, especially, the first two paragraphs.	1-128
Y	PLUCKTHUN, A. et al. New protein engineering approaches to multivalent and bispecific antibody fragment. (1997) Vol. 3, pages 83-105. Entire document, especially, Pages 96-99.	1-72
Y	US 6054312 (LAROCCA, D. et al.) 25 August 2000, columns 20-24, and Claims 1-15.	1-72, 75-77, 51, 129, 133-135, 137-140, 142, 144, 146.
Y	NOREN, C. J et al. Dissecting the Chemistry of Protein Splicing and Its Applications. (2000) Angew Chem Int Ed Engl., Vol. 39, pages 450-466. Entire document, especially see "summary" section.	1-72, 164-183
Y	MCGUINNESS, B. T. J et al. Phage diobody repertoires for selection of large numbers of bispecific antibody fragments. (1996) Nature Genetics, Vol. 14, pages 1149-1154. Entire document.	1-72, 73-92, 95-96, 99, 129.

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/45653

## C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Perler F. B. A natural example of protein trans-splicing. (1999) Trends Biochem Sci., Vol. 24, pages 209-211. Entire document.	1-72, 93-128.